SEPTEMBER 1959

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4 GROSVENOR GARDENS LONDON SW1

Established 1869 Incorporated by Royal Charter 1899

VOLUME 193 PART 1

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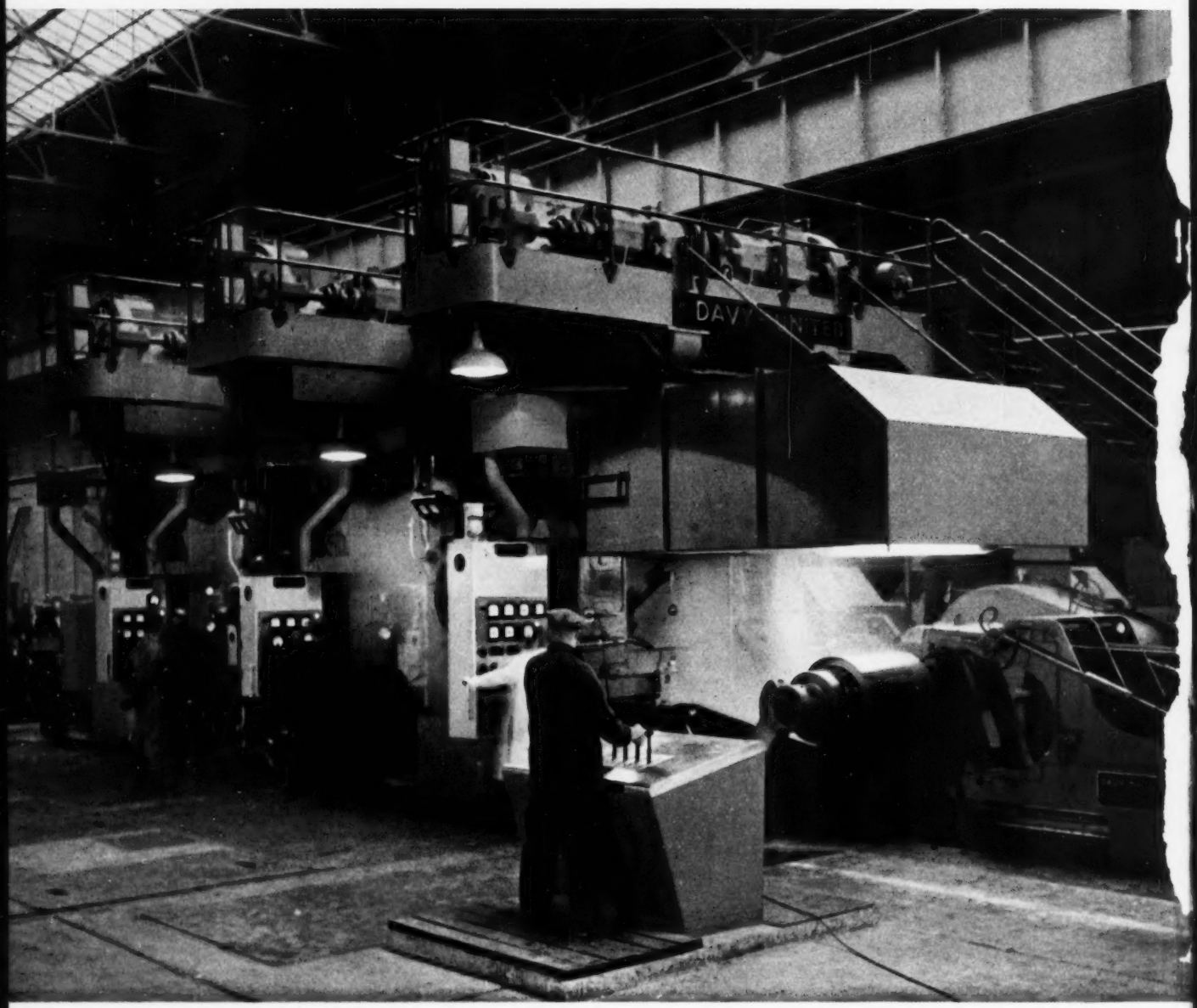
DAVY-UNITED

at RICHARD THOMAS & BALDWINS



3-STAND TANDEM COLD STRIP MILL FOR SPECIAL STEELS

This 16" and 49" × 42" Cold Reduction Mill, in the Cookley Works of the Midlands Section of Richard Thomas & Baldwins Limited, rolls various grades of silicon steel strip for electrical applications at speeds up to 850 feet per minute.

DAVY-UNITED

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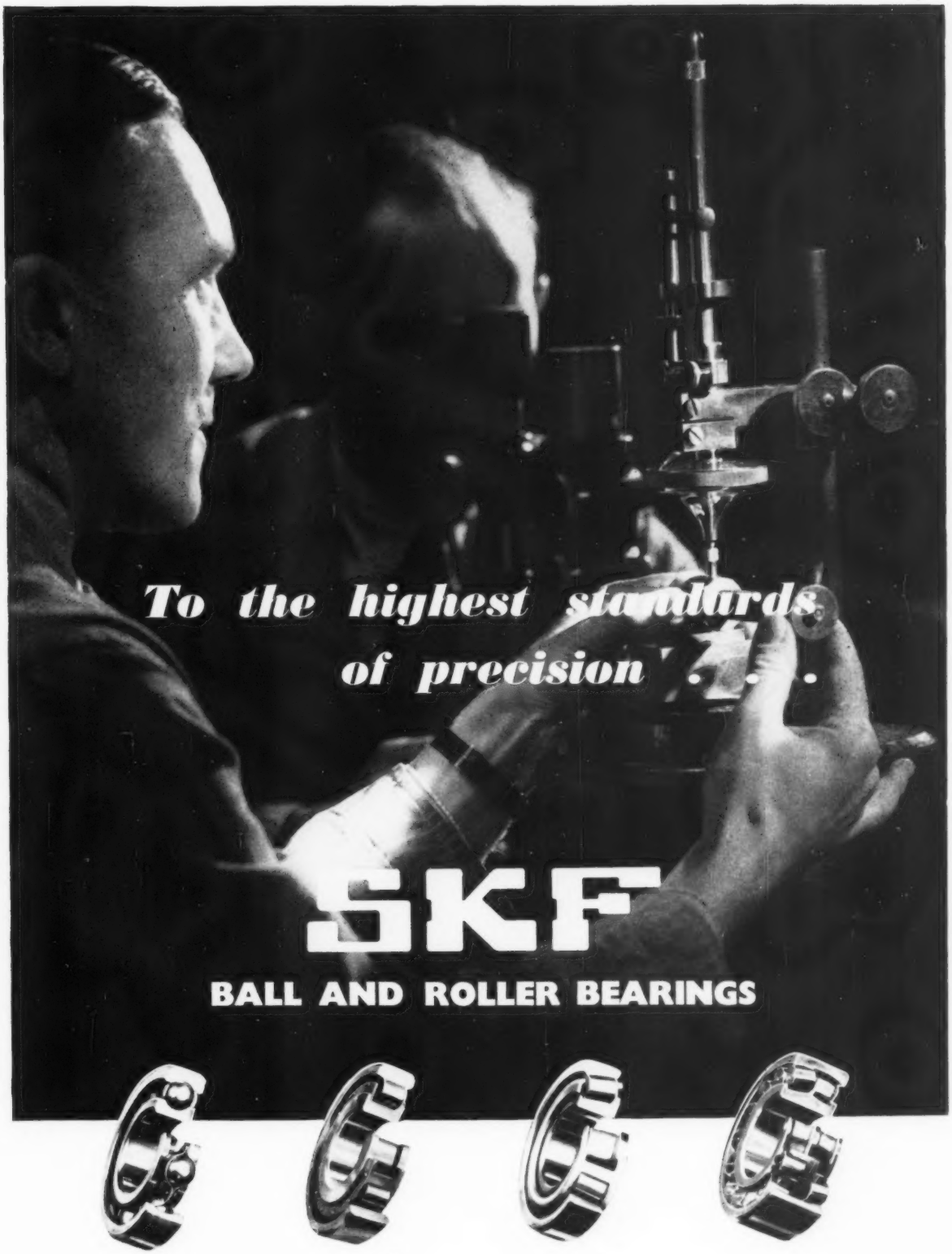
Middlesbrough
Glasgow

314/D.1



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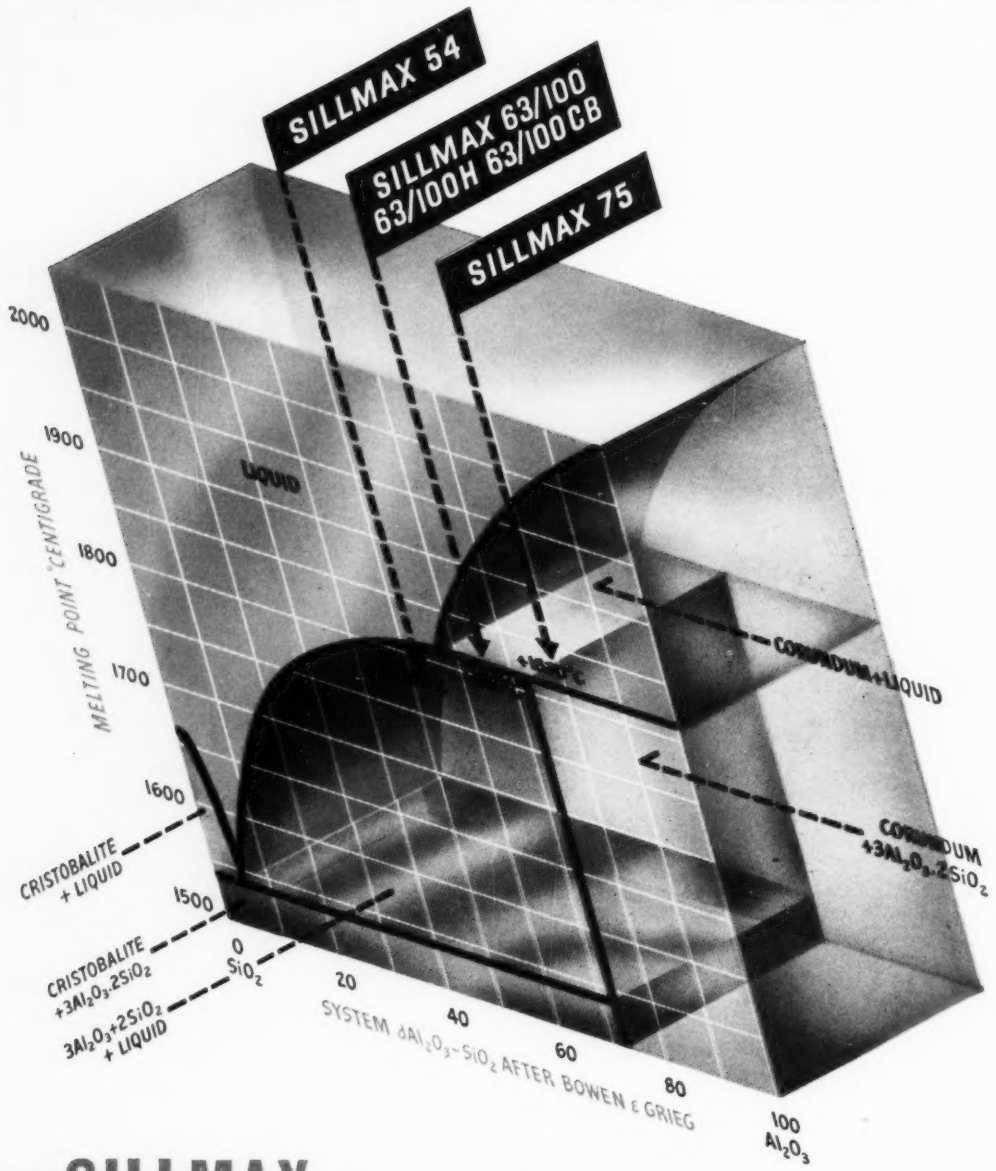
Liquid melt formation reduced to *NEW* low levels!



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Refractory products are designed to reduce liquid melt formation at operating temperatures to a minimum; this is achieved by the use of chemically pure raw materials high in Alumina such as Sillimanite, Kyanite, Corundum, etc. Modern brick making techniques coupled with high temperature firing produce the well known and proved range of SILLMAX BRICKS which is now available for use in a wide range of applications.

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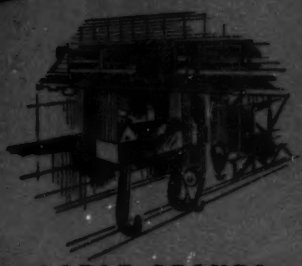
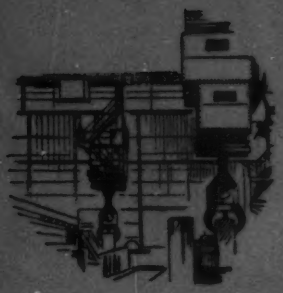
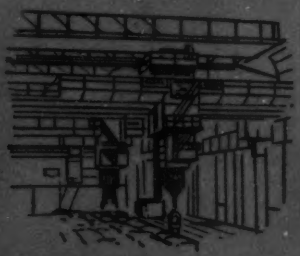


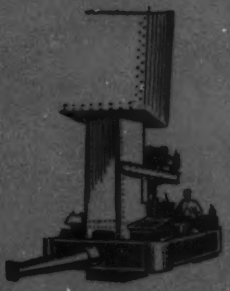
LADLE CRANES



SOAKING PIT CRANES



STRIPPING CRANES



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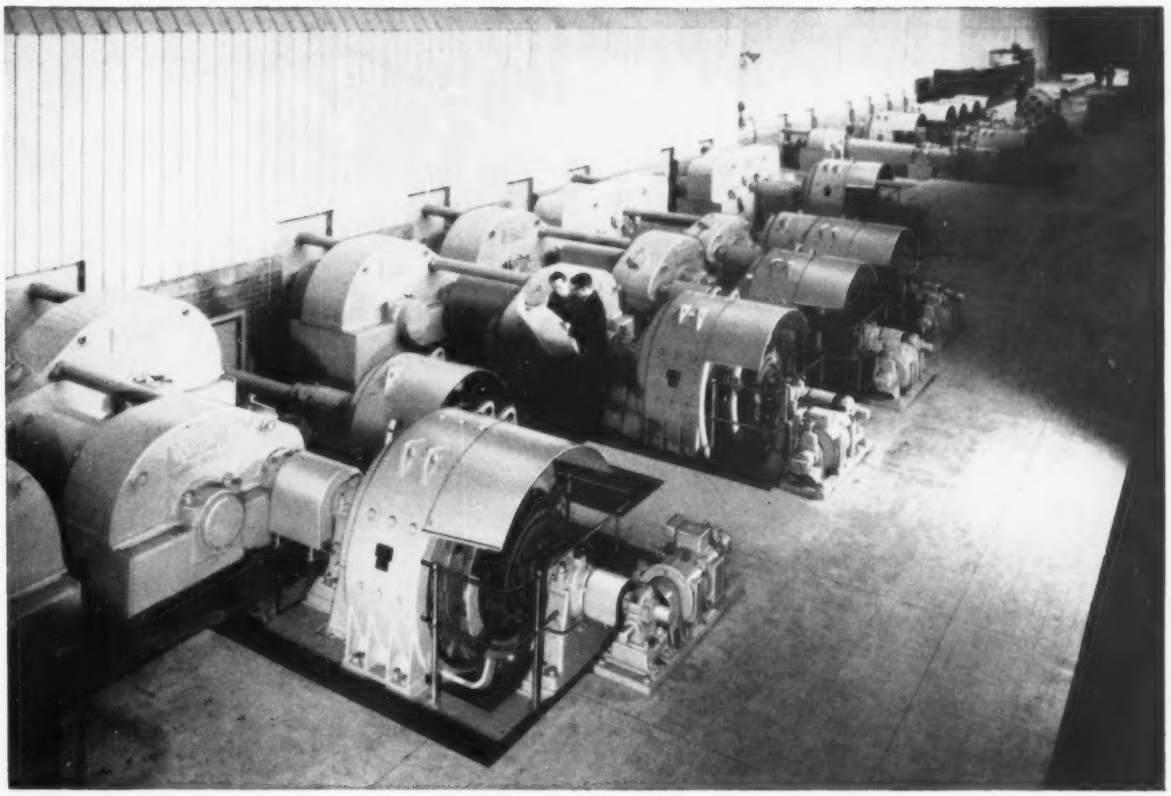

MILL DRIVES for DORMAN LONG

The electrical drives for the Lackenby Merchant Rod and Strip Mill of Dorman Long Steel Limited, Middlesbrough, were designed and installed by 'ENGLISH ELECTRIC'.

The mill having its own laying reels, cooling bed and strip reels is the most comprehensive of its type in Britain.

It is powered by drives totalling 9,200 h.p. R.M.S. fed from grid controlled, sealed steel tank, mercury arc rectifier equipments, with on-load tap-changers.

'ENGLISH ELECTRIC' also supplied drives totalling 2,000 h.p. for the billet mill and the 8,000 h.p., 432 metre-tons, 40/80 r.p.m. twin-drive for the blooming mill.

'ENGLISH ELECTRIC'

THE ENGLISH ELECTRIC COMPANY LIMITED, MARCONI HOUSE, STRAND, LONDON, W.C.2

Metal Industries Division, Stafford

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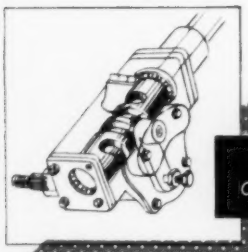
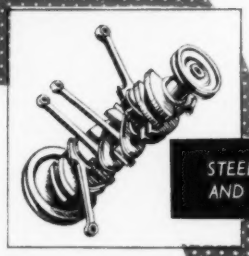
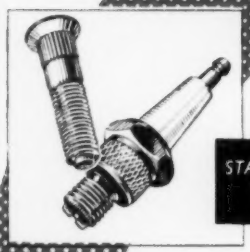


MILD, CARBON AND CASE-HARDENING STEELS



STEELS FOR FORGINGS AND DROP STAMPINGS



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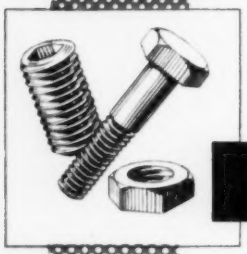
PARK GATE STEELS



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RANGE OF QUALITIES

Steels in the carbon range 0·08—0·85%
Case – Hardening Steels
Free Cutting Steels
Low Alloy Steels

RANGE OF PRODUCTS

Billets from 3″ square upwards
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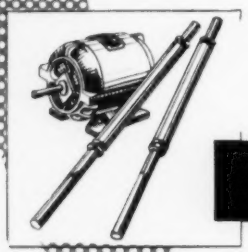
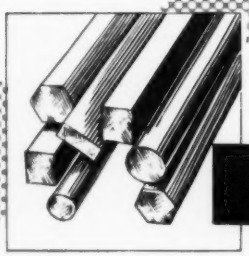
Hexagons $\frac{3}{8}$″ to $3\frac{5}{8}$″ Flats $1\frac{1}{2}$″ to 12″ wide
Coiled Bars $\frac{3}{8}$″ to $1\frac{1}{16}$″
Cold Forging Quality Wires
Colliery Arches, Props and Accessories



HARD SHAFT STEELS



MILD, CARBON AND ALLOY STEEL BARS

THE PARK GATE IRON & STEEL COMPANY LIMITED ROTHERHAM

A TI Company TELEPHONE ROTHERHAM 2141 (10 lines) TELEGRAMS: YORKSHIRE, PARKGATE, YORKS. TELEX 54141

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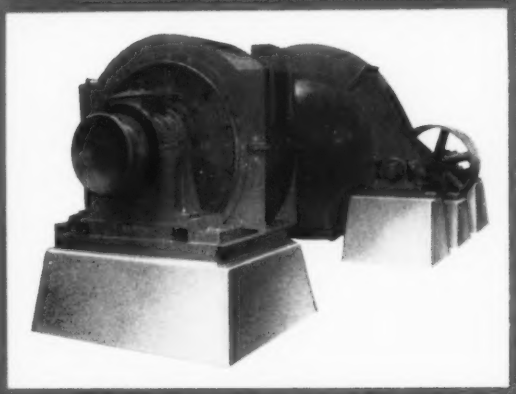
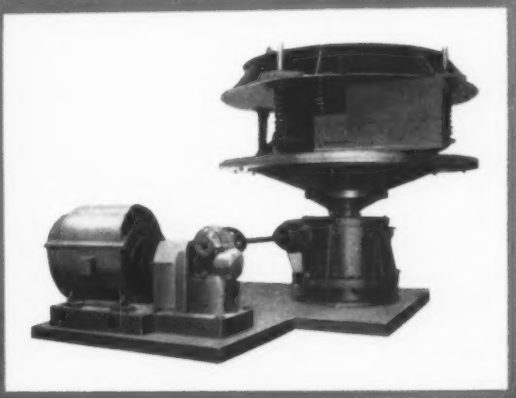


PATENT ROD MILLS FOR

grinding coke, breeze and other abrasive materials to required fineness, built in 7 sizes to suit outputs between 1 and 20 tons per hour.

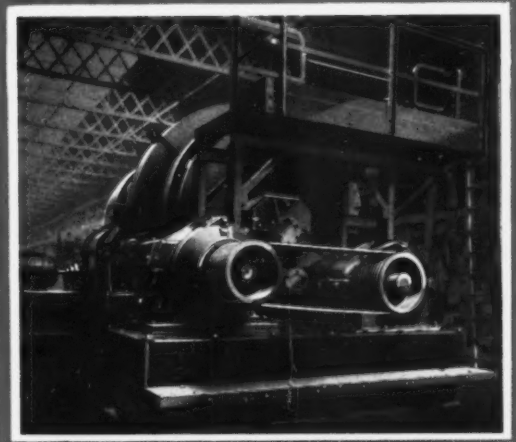


FEED TABLES FOR

accurately proportioning iron ore fines, crushed coke, flue dust etc. Built in several sizes to suit customers silos and output requirements.

ROTATING DRUM TYPE PELLETISER + CONDITIONER FOR

sinter materials, sizes and designs to meet individual requirement.



PATENTED ROTATING DRUM + MULTI-SCROLL MIXER FOR

thoroughly mixing iron ore fines of varying densities and moisture contents, coke, breeze, flue dust and scale etc. for mixed feed to sinter strands. Designs for outputs up to 500 tons per hour.

Newells

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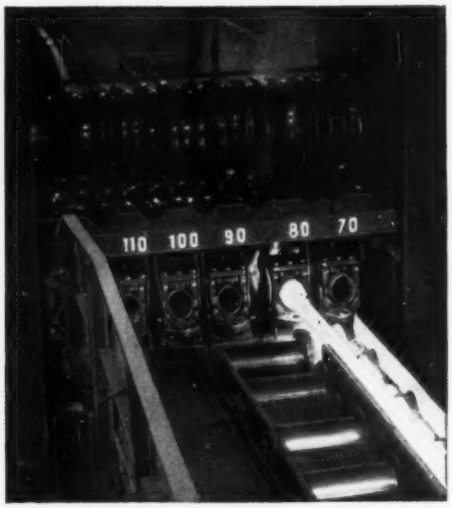
Ernest Newell & Co. Ltd., MISTERTON VIA DONCASTER.

8 good reasons why you should use these ROLLER GUIDES in your bar or wire rod mill



Nos. 125 and 155 roller guides fitted in a 27 1/2 in. (700 mm.) diameter, three-high stand for rolling 2 3/4, 3 3/16, 3 9/16, 4, 4 3/8 and 4 7/8 in. (70, 80, 90, 100, 110 and 124 mm.).

1 The entry friction guides are rigidly clamped into the guide box. They are intended to lead the oval to the groove in the roller, to protect the rollers against overloading, and to straighten bent rods.
The groove in the entry guides is made about 1/8" wider than the oval.

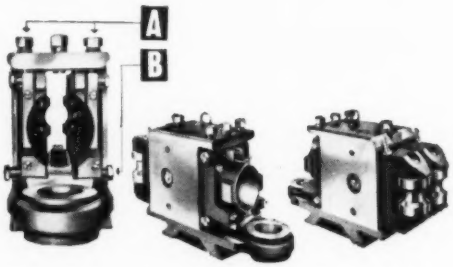
2 The rollers are mounted on leaf springs, which can be adjusted by means of the screws "B", and hold the oval steadily even if there should be some slight variation in the thickness of the oval.

3 If the thickness of the oval should vary, the springs of both rollers yield an equal amount, so that the oval remains in the centre of the groove.

4 To tilt the oval, the screws "A" are adjusted. One roller will then be lifted as much as the other is lowered.

5 As the oval is held very rigidly, the leader oval for wire rod may be thick, unless other circumstances call for a thinner oval.

6 The roller guide assemblies are narrow, and all screws that require adjustment during rolling are accessible from the front of the mill. No lateral space outside the guide box is therefore required for gaining access to the set screws, and the guide box assembly can thus be located close to the mill housing.



7 As the groove in the entry guides is wide and nothing but rolling friction acts on the oval, the latter is very easily introduced into the pass, and there is practically no risk of scratching the bar.

8 The roller guide may be used not only for leader and drawing oval passes but also for edging flats as well as for rolling squares, hexagons, octagons and various other sections, for instance in reduction passes for hexagon. It is suitable for all types of rolling mill. An important advantage is that the roller guide enables repeaters to be used in rolling plump leader-ovals.

PS *Practically speaking, every bar and wire rod mill in Scandinavia uses roller guides of our design.*

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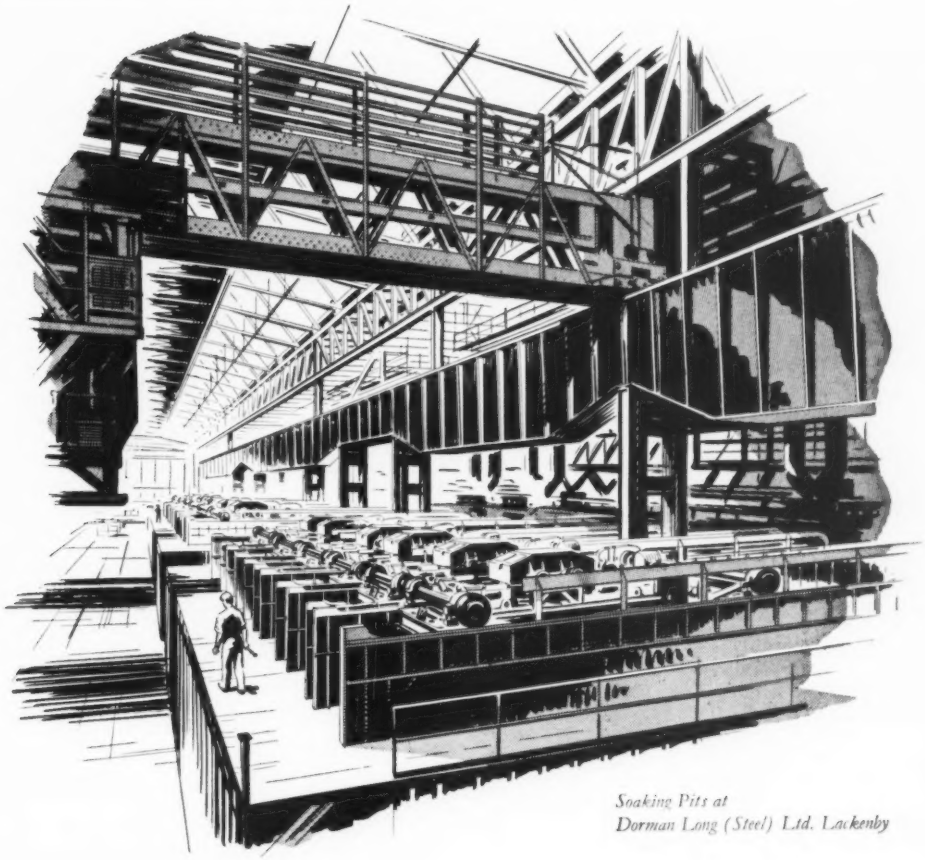

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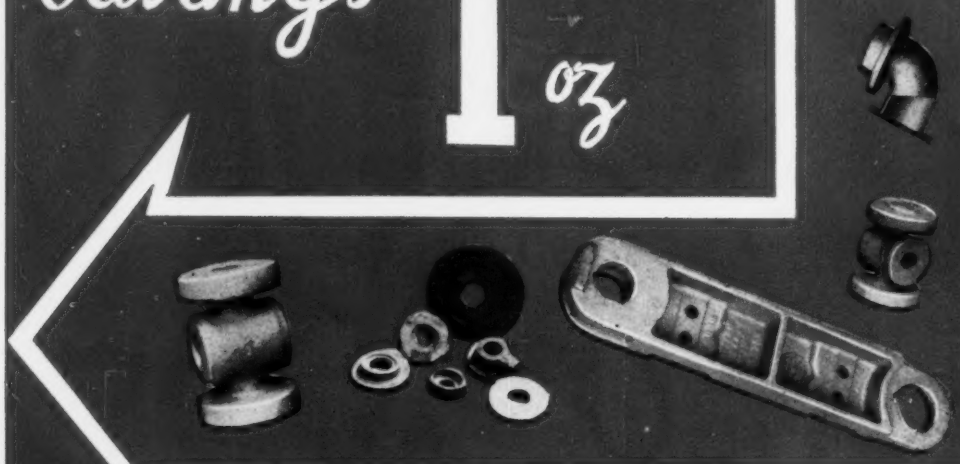

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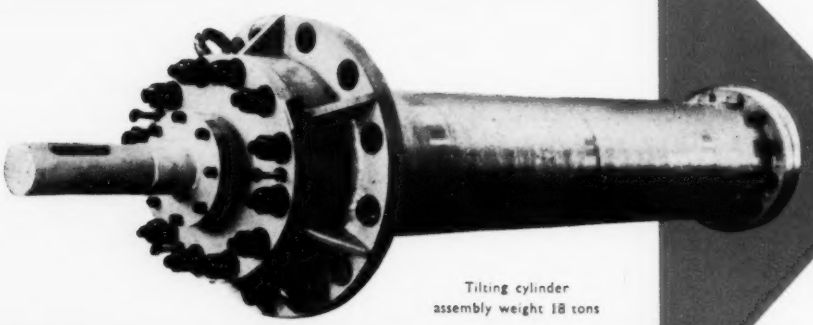
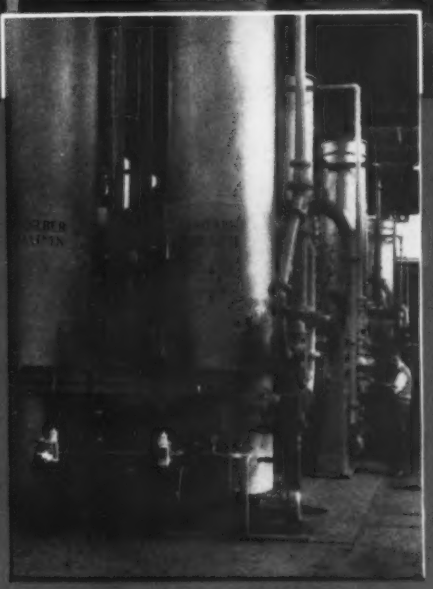


Tilting cylinder assembly weight 18 tons

HADFIELDS
SHEFFIELD

HADFIELDS LTD., EAST HECLA WORKS, SHEFFIELD

The above illustration shows a general view of the annealing furnaces, installed for the Steel Company of Wales at Velindre Works. The illustration on the right shows the H.N. Atmosphere Gas Plant also installed by Salem at Velindre Works.



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Salem design, build and put into operation complete plant with all ancillaries.

Salem

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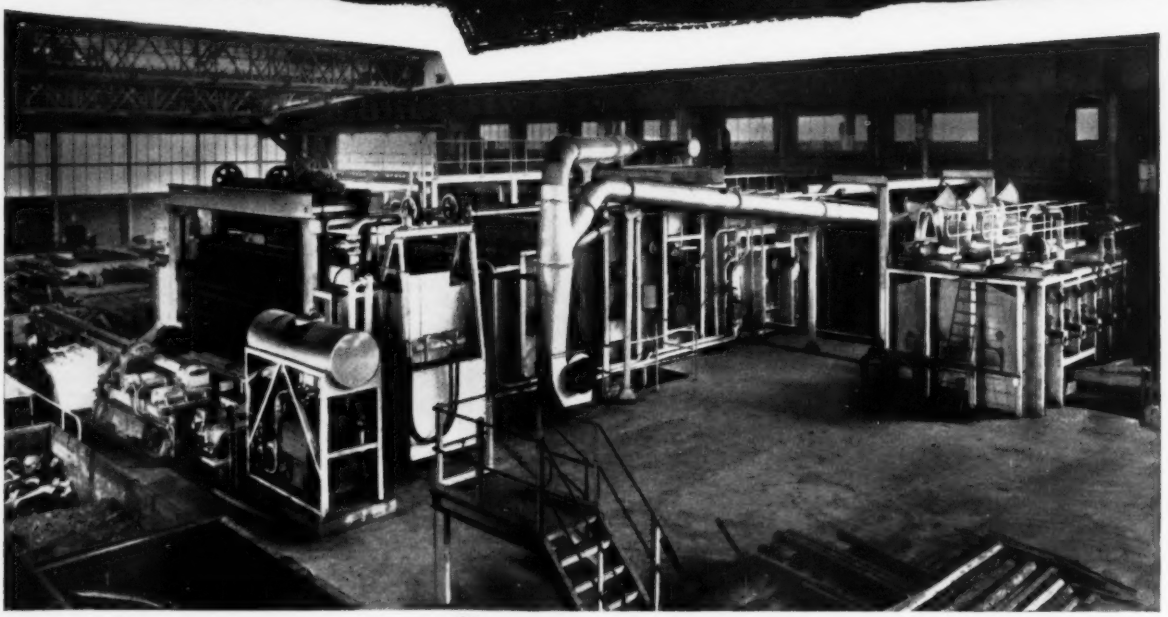
CRAFTSMANSHIP

PRIEST

Oil Fired Continuous Billet Heating Furnace



We specialise in the design and construction of:—

Open Hearth Furnaces · Soaking Pits of all types · Continuous Multi-zone Bloom and Slab Re-heating Furnaces · Continuous Bogie type Ingot and Slab Heating Furnaces · Furnaces for Aluminium Melting, Coil Annealing and Slab Re-heating · Forge and Heat Treatment Furnaces · Stress Relieving Furnaces · Shipyard Plate and Bar Furnaces · Modern Lime Burning Kilns

The above Furnace is for reheating $3\frac{1}{2} \times 4$ in. billets 12 ft 0 in. long to rolling temperature. Specifically designed and zoned for efficient operation over a varying range of output up to a maximum of 25 tons per hour. Supplied to Samuel Fox & Company Limited, Stocksbridge Works, Sheffield, complete with electro-hydraulic pusher, side discharge pusher, extractor rolls and charging roller table.

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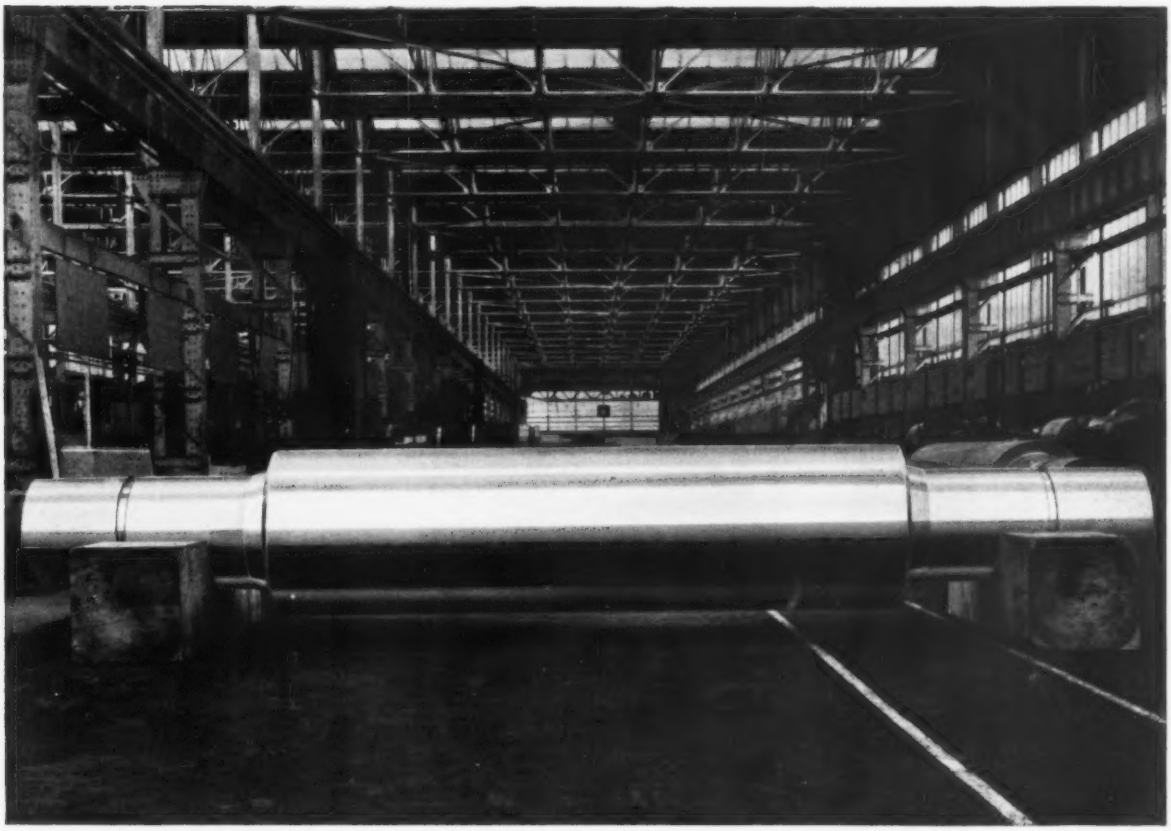
PRIEST
The last word in Furnace design

CRAFTSMANSHIP BY THE TON



This heavyweight turned the scales at 28 tons, 10¼ cwts. It is a Duplex Manganite Alloy Indefinite Chill Work Roll, 39″ × 150″ × 266″, for a 4 High Plate Mill. From this, to the smallest work roll, you can rely on us for accuracy and quality.

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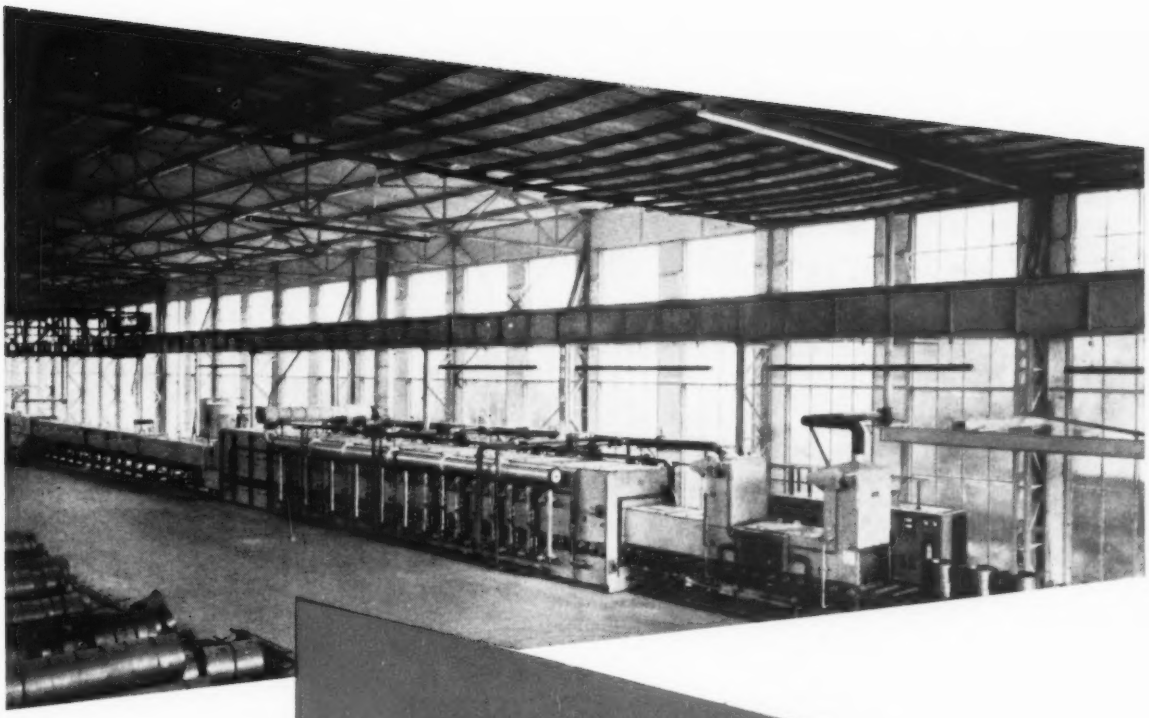

NASSHEUER

continuous bright annealing

FURNACES

(British Patent No. 719669)

INCREASE PRODUCTION AND QUALITY LOWER MAINTENANCE AND OPERATING COSTS, OUTPUT UP TO 5 TONS PER HOUR, GAS OR ELECTRICALLY HEATED

Suitable for:—

Strip in Coils
Wire Coils
Bar Materials
Sheets in batches or singly
Tubes
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Brush or Spray Rust-Oleum 769 Damp-Proof Red Primer Right Over Sound Rusted Surface.

Save costly metal replacement, and beautify as you protect, with famous Rust-Oleum made in United States of America. If the surface is rusty — apply Rust-Oleum 769 Damp-Proof Red Primer right over the sound rusted metal — after scraping and wirebrushing the rust scale and loose rust away. The *specially-processed* fish oil vehicle penetrates rust to bare metal — driving out air and moisture. It dries to a tough, firm, decorative finish that lasts and lasts. Proved throughout American industry for over 35 years. You save costly metal — and you save costly surface preparations as sandblasting and chemical cleaning solutions are usually eliminated.

Beautify As You Protect With Rust-Oleum's Wide Variety Of Colorful Finish Coatings.

Rust-Oleum finish coatings are available in Red, White, Gray, Blue, Green, Black, Aluminum, Yellow and many other colors. Used over the Rust-Oleum 769 Damp-Proof Red Primer — they provide the maximum in lasting beauty on tanks, pipes, towers, girders, equipment, machinery, stacks, metal fences, sash, boilers, and other rustable metal. The Rust-Oleum distributor listed below maintains complete Rust-Oleum stocks for prompt delivery to you. He welcomes the opportunity to tell you about Rust-Oleum and will be happy to provide you with a complete Rust-Oleum Color Catalog and a free test sample. Ask him for a demonstration on your own rusty metal.

Rust-Oleum saves rusty tanks, metal sash, metal fences, fire escapes, boilers, pipes and fittings, equipment, etc.

Proved for over 35 years and manufactured in accordance with the famous RUST-OLEUM exclusive formula in the United States of America by

RUST-OLEUM CORPORATION, 2433 Oakton Street, Evaston, Illinois

Immediate delivery from

MESSRS. STEDALL & CO., LTD.

192/204 Pentonville Road

London, N.1

FOR A COMPLETE CATALOG AND FREE TEST SAMPLE ATTACH COUPON TO YOUR LETTERHEAD AND MAIL TO RUST-OLEUM DISTRIBUTOR SHOWN AT LEFT!

Gentlemen: Please send me the following at no cost or obligation.

- ☐ Complete Catalog with actual color charts.
- ☐ Free test sample of 769 Damp-Proof Red Primer to apply over sound rusted metal.
- ☐ Please have your representative call to give me a Rust-Oleum demonstration.
- ☐ Finish Colour desired in FREE TEST SAMPLE—

_____

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Iron and steel producers and stockholders use SMITH CRANES to handle material in the scrapyard and the stockyards. A typical example is this 7-ton capacity Smith diesel-electric loco crane shown working with magnet equipment.

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NEW
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for protection
and performance
no other oil
can equal

ASK THE MAN FROM MOBIL

This line is no exaggeration. It is the plain truth, proved in careful tests against other well known hydraulic and circulating oils. The line down our left-hand margin is taken from a chart of these tests. Ask your Mobil representative to show you the chart. He will explain how, on *balance*—on the results of all the tests—new Mobil DTE Oils show a clear advantage that can mean lower costs and improved production in your business.

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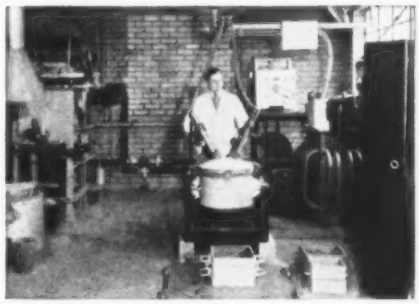

We invite you at any time to call on the services of our experimental foundry and sand-testing laboratory. Our foundry technicians will be pleased to co-operate in helping you find the solution to sand casting problems. Or if you prefer, they can come to your foundry to discuss a particular difficulty on the spot. These Fulbond services are offered without charge. All details are, of course, treated in strict confidence.

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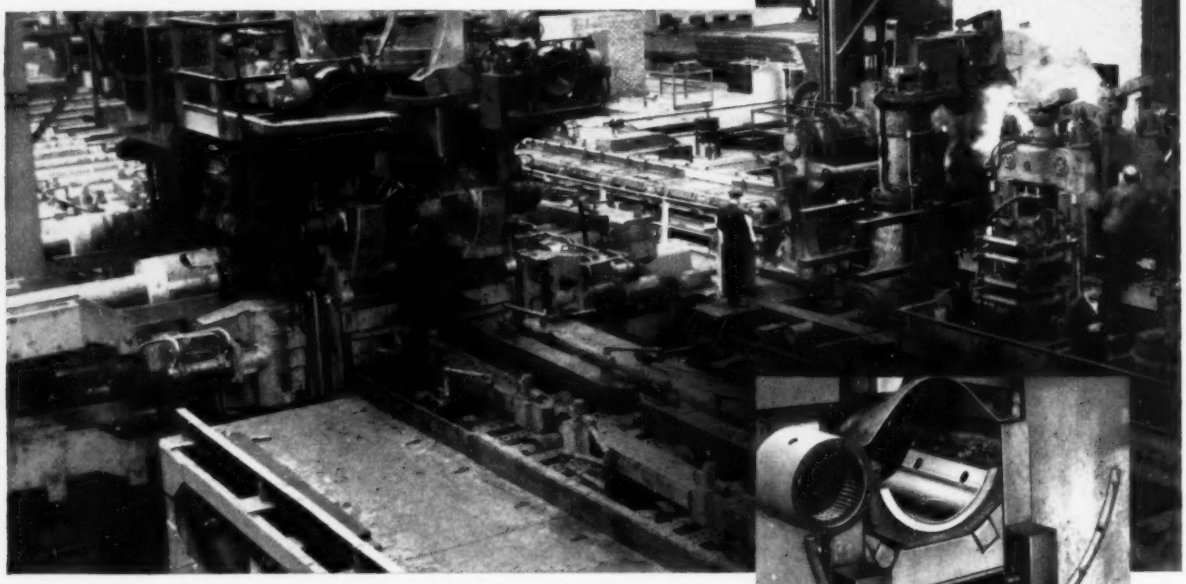
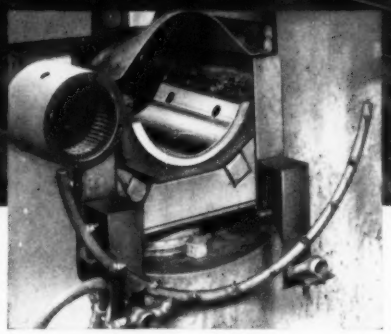
Railko Bearings at Lackenby—





Roll stand during Roll changing period. Lower Railko bearing in position with water spray.

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At the Lackenby works of Dorman Long – most modern in the world for the rolling of steel sections – the production of a new and wide range of beam and column sections opens up immense new possibilities for designers and constructional engineers.

In many places where extremes of temperature and pressure are met the performance of bearings of conventional materials would be unsatisfactory. To overcome these problems Railko bearings are specified and have proved completely suitable.

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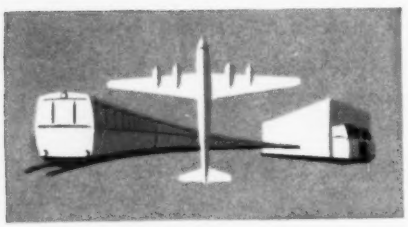
Railko bearings have many advantages. They withstand extreme pressure and movement * have a high strength-to-weight ratio * a high compressive strength * a low co-efficient of friction * can be lubricated with a variety of fluids * in certain applications can be used without fluids * are resistant to acids and alkalis * have a low rate of wear * are easily machined * have excellent weathering properties.



Railko bearings are now widely used by manufacturers in the steel, railway, aviation, engineering and chemical industries. Perhaps they can help *you*? Write to us and we shall be glad to send you full technical details.

Railko bearings help every industry–**Land-Sea-Air**

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The efficient movement of materials and components is a job for the expert — it is *not* a problem for you to worry about. We, at KING'S, have for 40 years been solving these problems of materials handling and we like to think we know most of the answers.

Call us in, we'll take the load off your mind!

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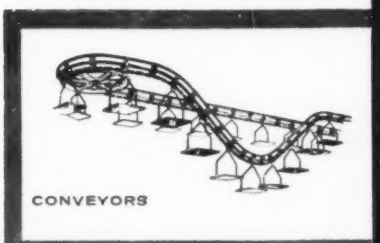

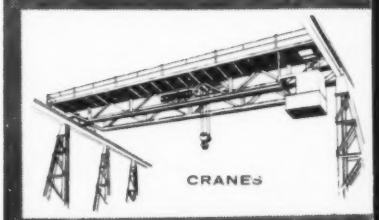

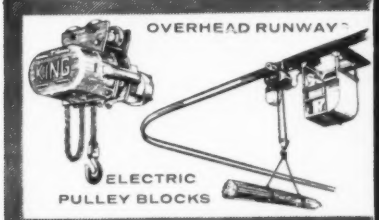

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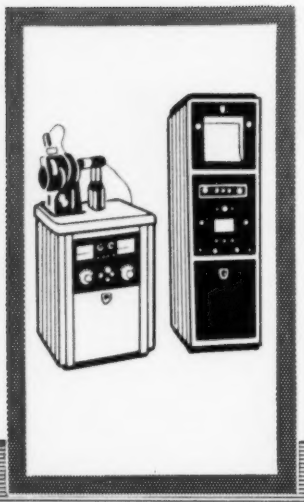

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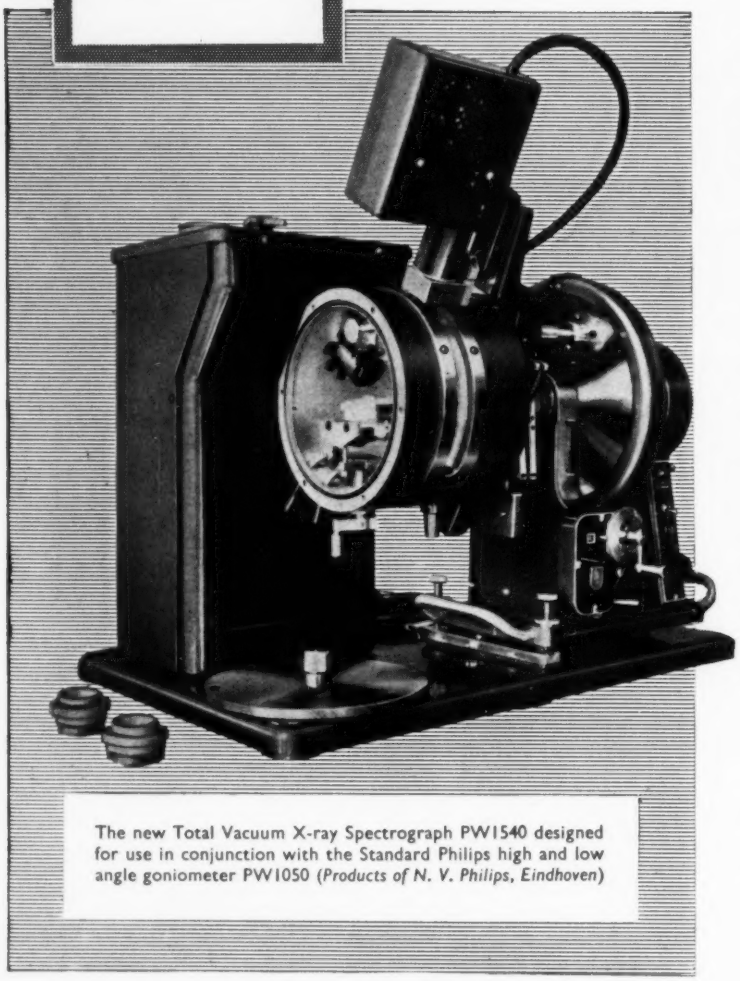
NOW—DOWN TO MAGNESIUM!



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Special features of Philips PW1540 Total Vacuum Spectrographic Attachment:—

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2. Built-in flow proportional detector.
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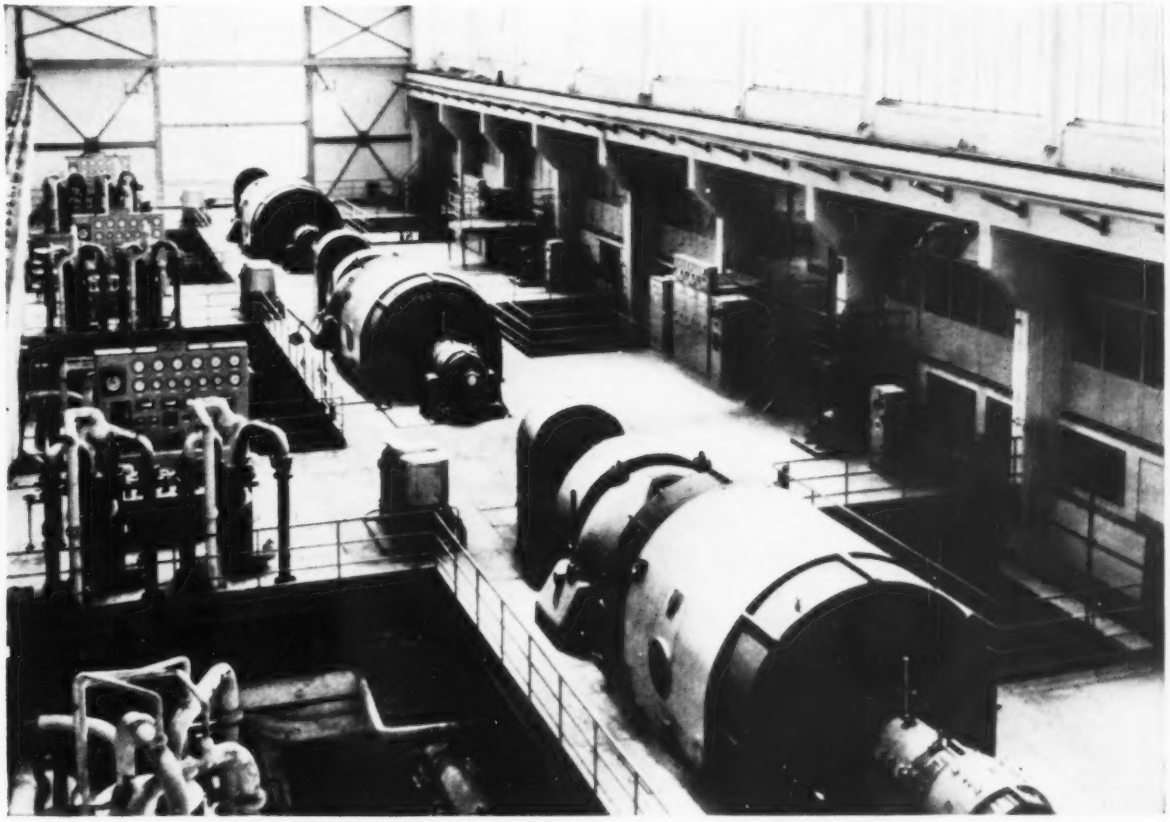

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The National Coal Board, North Eastern Division, No.4 (Carlton) Area, Grimethorpe Central Power Station houses three 20,000 kW PARSONS turbo-generators, each complete with condensing plant and feed water heating system. These 3,000 r.p.m. single cylinder turbines are fitted throughout with reaction blades and are designed to operate with inlet conditions of 400 p.s.i.g. 800°F and an exhaust vacuum of 28.0 in. Hg. (Bar 30 in Hg.) at the maximum rating.

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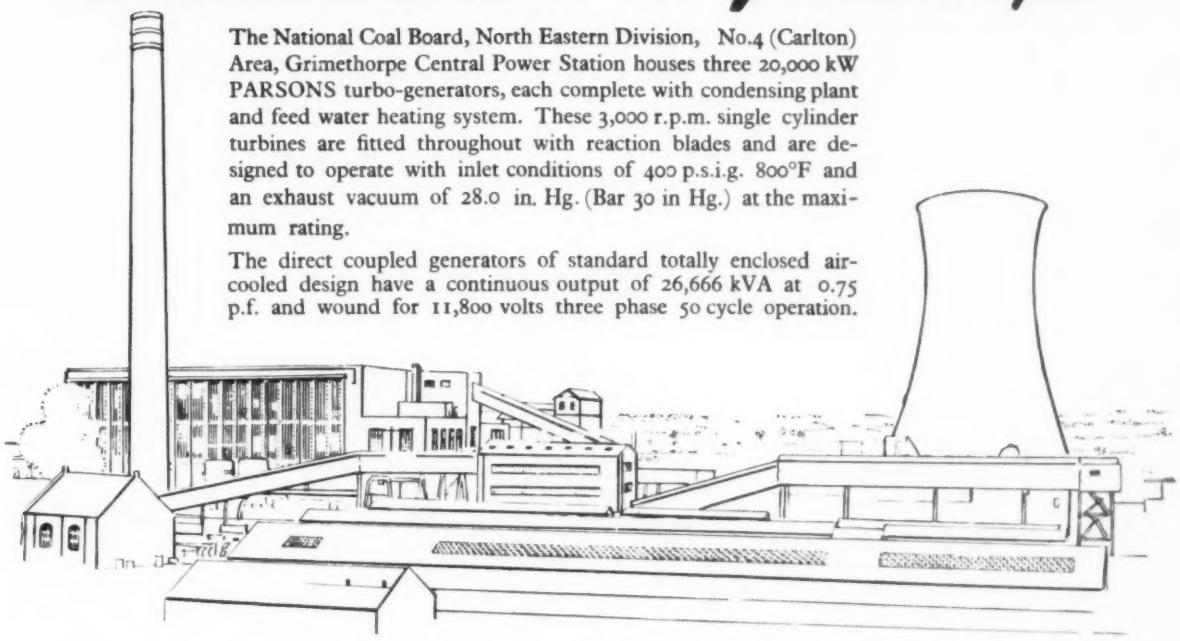

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TURBO GENERATORS • TURBO BLOWERS • POWER TRANSFORMERS • CONDENSING PLANT

Size: 12¼" x 9½" x 6⅜"
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Developed from the long and successful line of Foster Portable Potentiometers now comes Model 3155, which retains all the outstanding features of the previous models despite reduction in size and weight by over 50%. Main scale remains 14" long, cold-junction scale 6" long.
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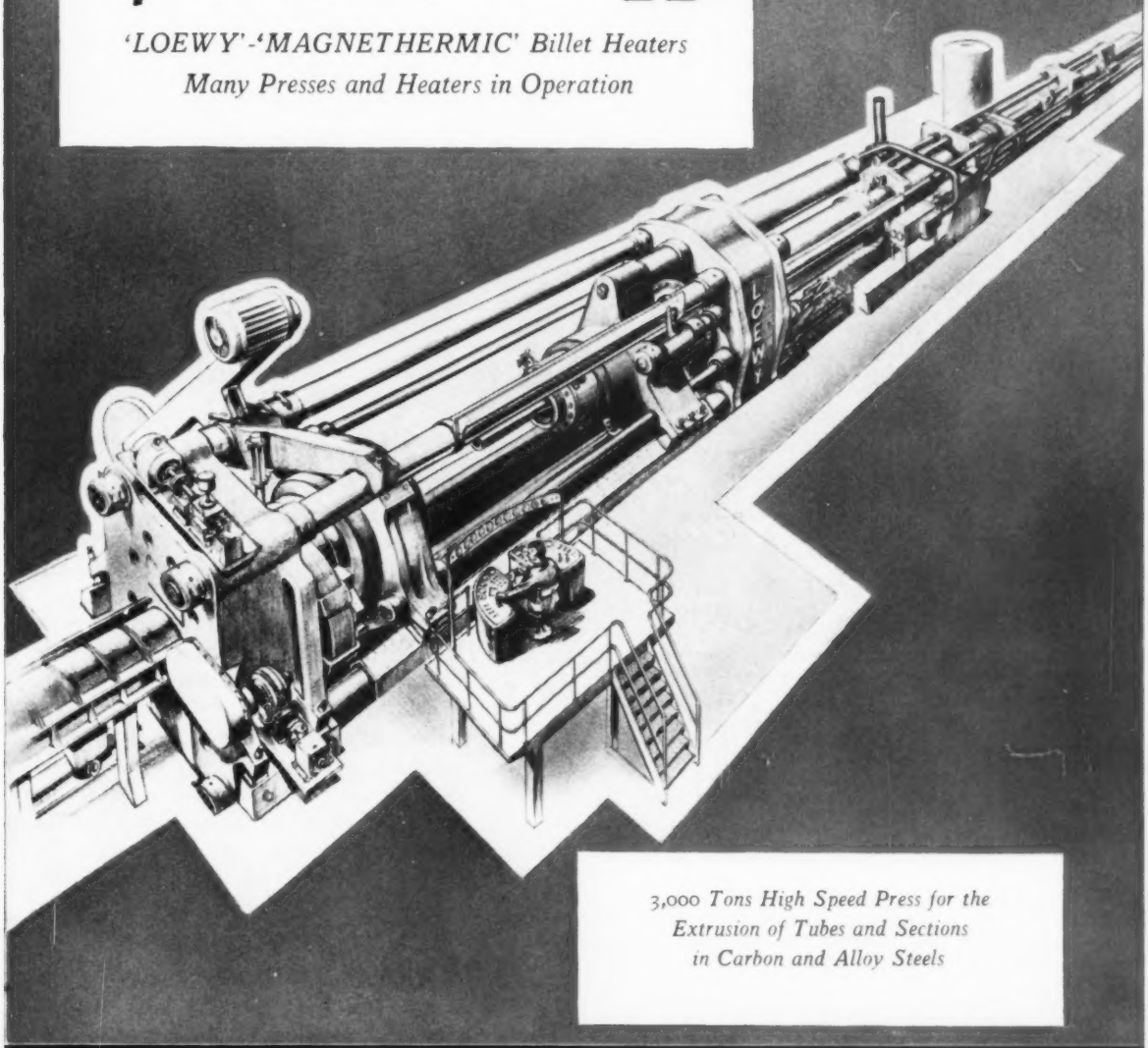

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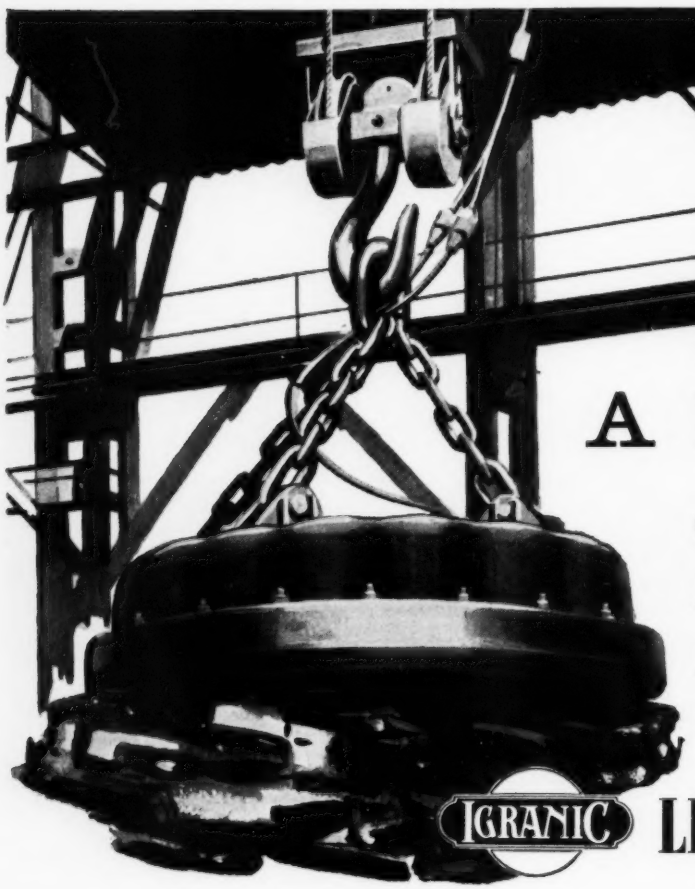

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24″ Light duty model	(slabs up to 6,500 lb.)
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77″ Supermagnet for extra high tonnages	(slabs up to 110,000 lb.)

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Also Multi-polar coil-lifting magnets and plate-lifting magnets for fork lift trucks.

The amazing power of IGRANIC magnets means quicker lifts, bigger loads on all ferrous-metal handling jobs from scrap turnings to steel slab, girders to coiled strip. The 77″ supermagnet—biggest in the world—will lift up to 110,000 lb. slabs with ease! Where else can you find such strength—such long life too? For IGRANIC magnets have many exclusive features for extra toughness, trouble-free service. Moisture problems are *out*—for IGRANIC magnets are *waterproof*, with a one-piece monolithic coil and double-sealed terminal boxes. Anti-wear devices prolong lifting chain life too and all parts are ruggedly made to resist rough handling and high temperatures.

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First for metal handling for over 40 years

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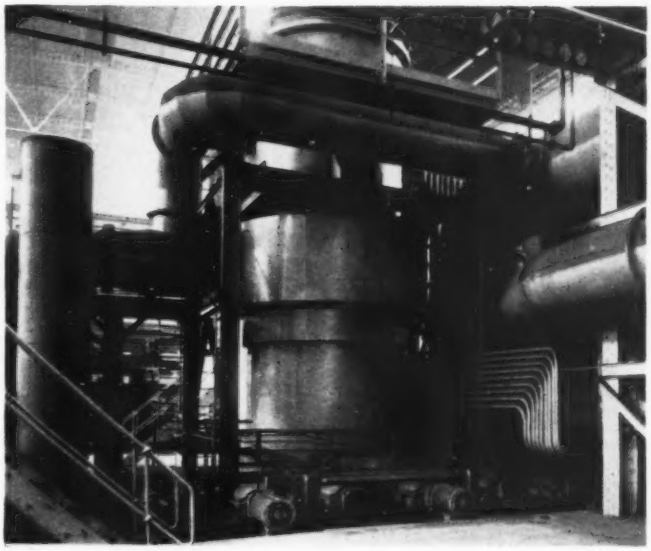
M.E. Flue Tube Recuperators for Reheating Furnaces



One of two M.E. Flue Tube Recuperators supplied to Stein & Atkinson Ltd., for two oil fired slab reheating furnaces, each with a capacity of 60–70 tons per hour, built by them for the Brinsworth Medium Strip Mill of Steel, Peach & Tozer Ltd. Each recuperator heats 1,140,000 c.f.h. of combustion air to 400° C.

M.E. FLUE TUBE RECUPERATORS HAVE THE FOLLOWING ADVANTAGES

1 They are supplied as an easily erected single unit of all steel welded construction, pressure tested in our Works to twice the working pressure.

2 The flue gases pass through plain bore seamless tubing which can easily be cleaned.

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Metallurgical Engineers LTD

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Would metals with such characteristics make your production better? Wild-Barfield—NRC vacuum melting furnaces enable you to develop materials specially suited to your needs. Backed by the experience of the National Research Corporation, who have built and operated more high vacuum furnaces than any other company in the world, Wild-Barfield—NRC vacuum equipment covers most needs. Write for details of the range.

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VACUUM INDUCTION FURNACES
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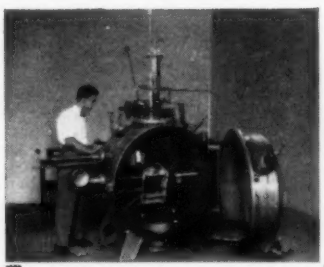
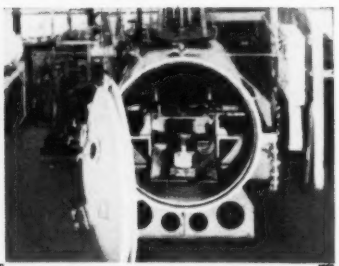


Model 2555 Vacuum Induction Furnace with melting capacity of 50 pounds of steel. Other standard furnaces have capacities of 12 to 3,000 pounds.



Model 2705 Non-Consumable Arc Skull Furnace with a capacity of 50 pounds of titanium. Other standard vacuum arc furnaces have capacities of 8 to 10,000 pounds of titanium.

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for **all** ***heat-treatment purposes***

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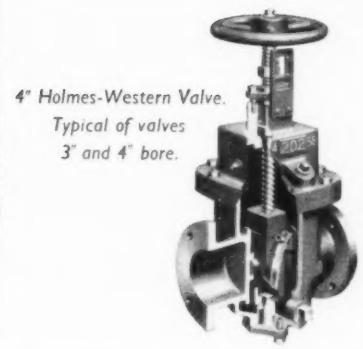

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Typical of valves
3" and 4" bore.

Gas Valves

From 3" bore to 48" bore

- ✱ **Double discs give double security.**
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24" Holmes-Western Valve.
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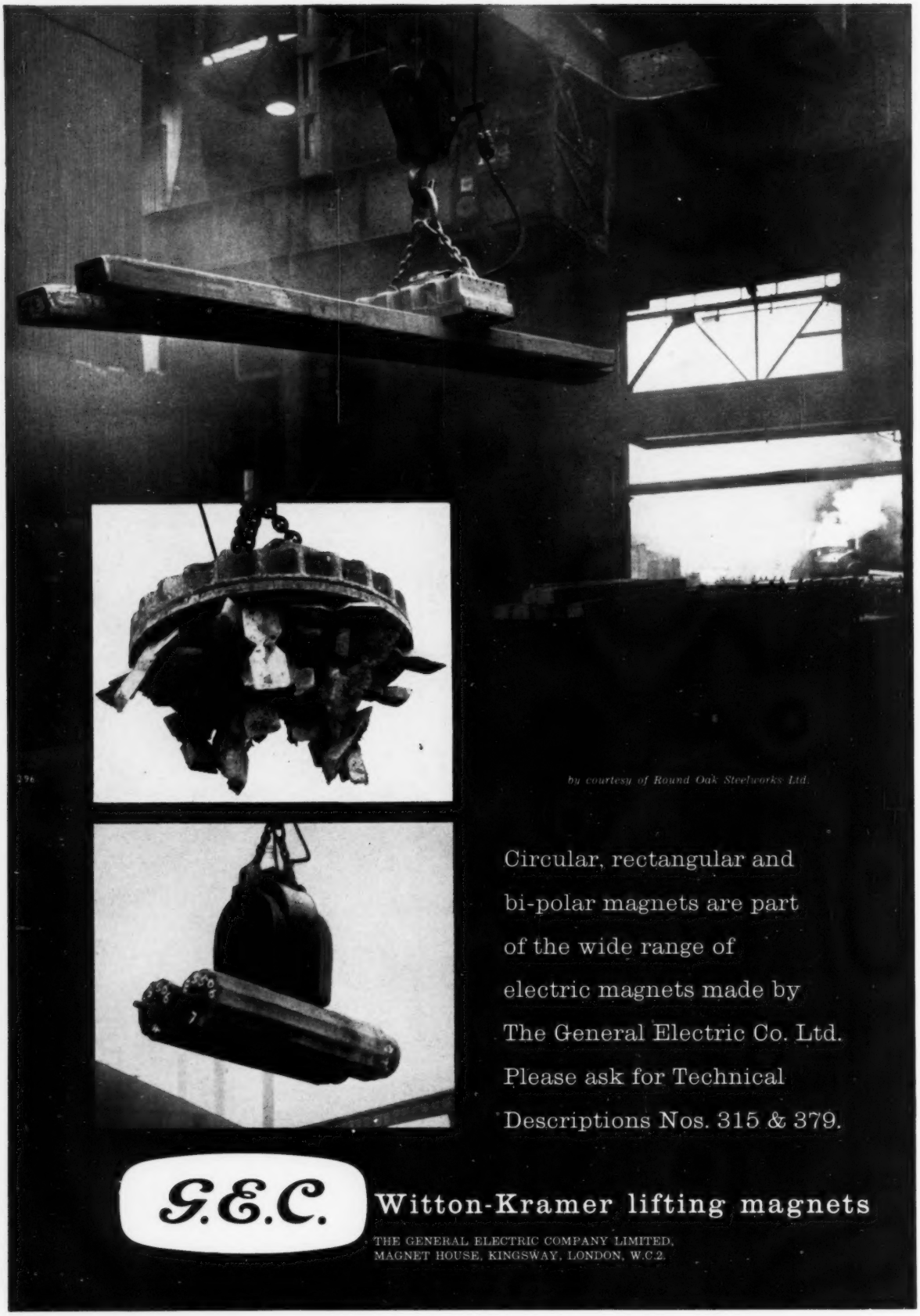

by courtesy of Round Oak Steelworks Ltd.

Circular, rectangular and bi-polar magnets are part of the wide range of electric magnets made by The General Electric Co. Ltd. Please ask for Technical Descriptions Nos. 315 & 379.

G.E.C. Witton-Kramer lifting magnets

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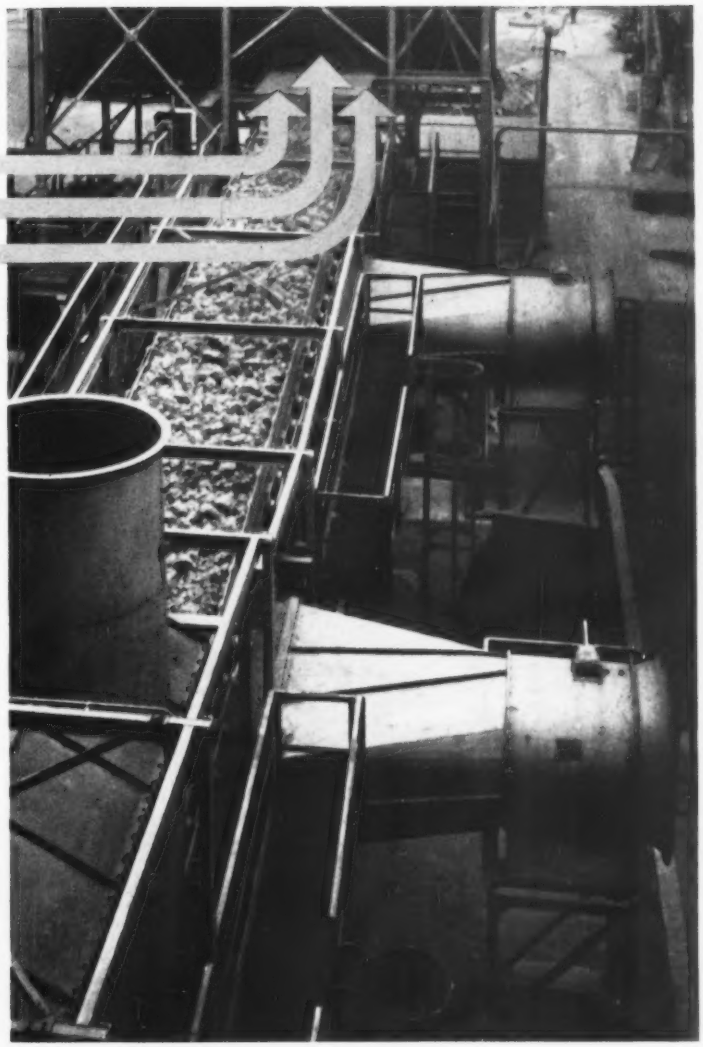
SPEEDING THE SINTER FLOW

This photograph was taken looking down on the sinter conveyor at Barrow Ironworks. On the right of the conveyor can be seen two of the three fans which have reduced the cooling interval so efficiently



For 70 years, we have made steady improvement in the sintering process our business, and each sinter plant we design and install incorporates the latest developments in sintering technique.

At many new sinter plants, including those at Barrow Ironworks, Consett Ironworks, the Iron and Steel Corporation of South Africa, Cockerill-Ougrée (Belgium) and the Société Métallurgique de Normandie (France), a new Huntington Heberlein cooler has increased the efficiency of the sinter process. High quality sinter is being cooled in 20 minutes from 600°C for transmission on normal belt conveyors. This cooling is achieved by forced circulation from cold air fans which work at very low power consumptions.

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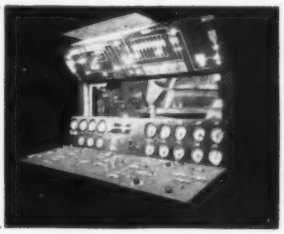
The feed rate control panel at Barrow



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S&L THE STEEL TUBE AGE

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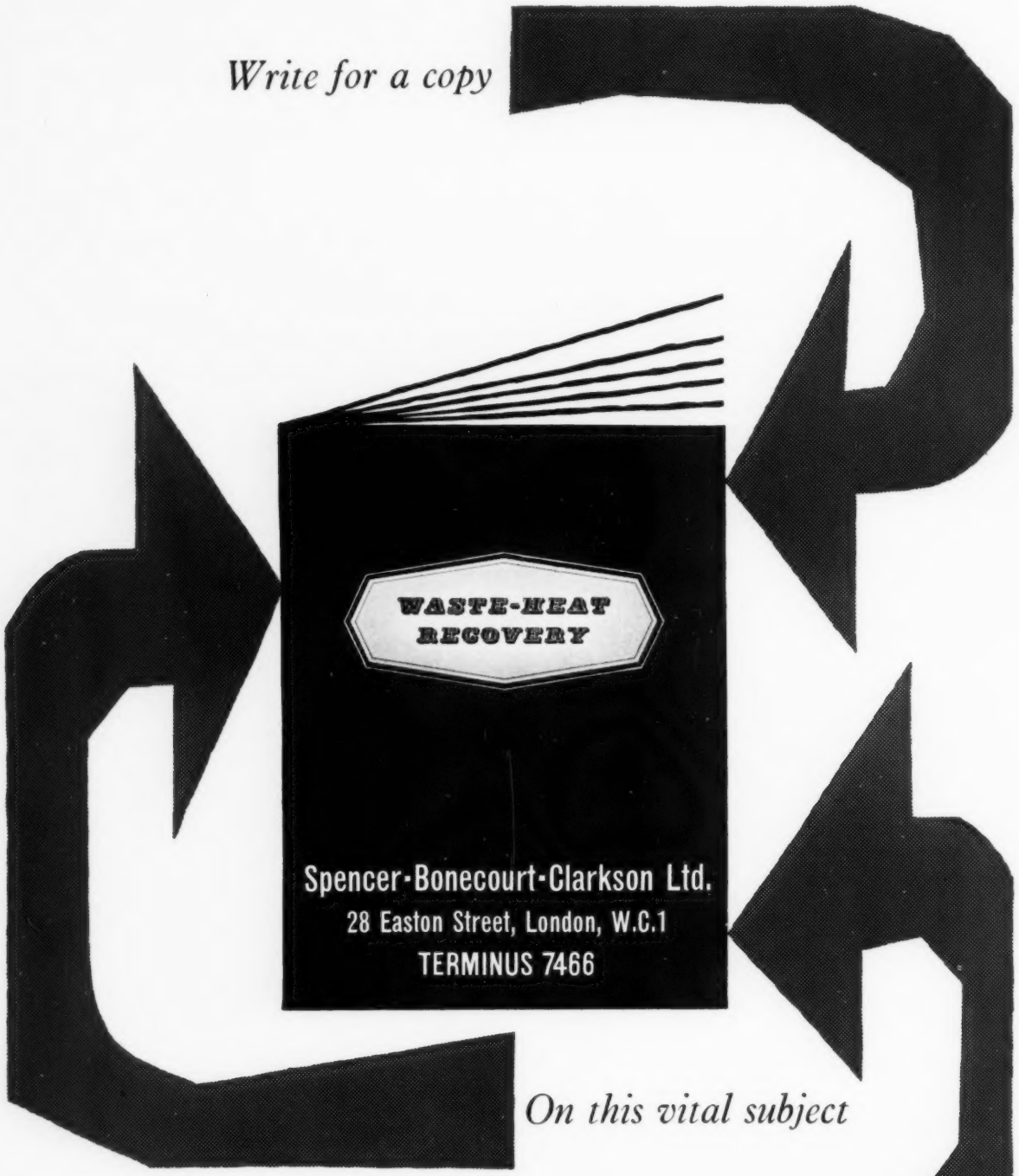
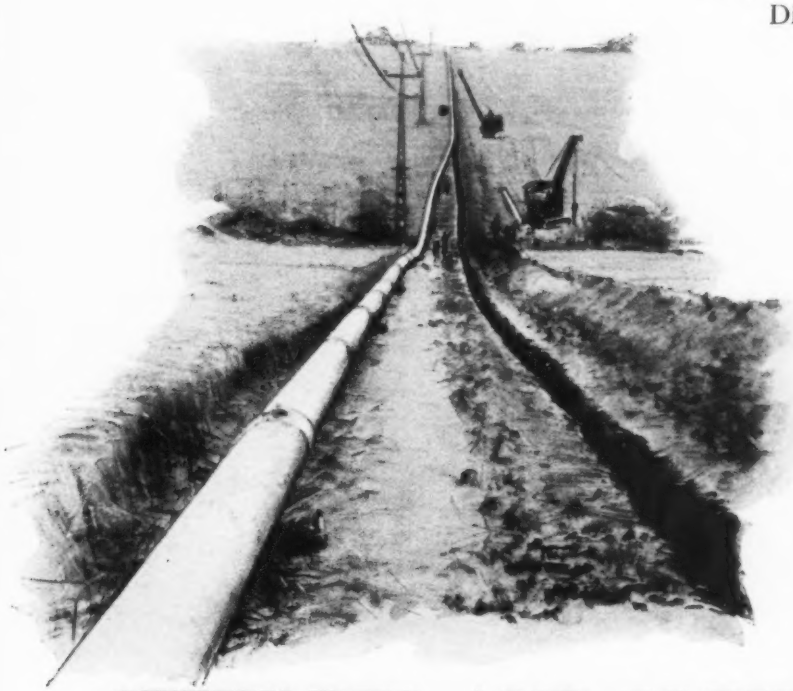


On this vital subject

These are the people to talk to

S&L THE STEEL TUBE AGE

At top, welding the pipes. Below, welded pipeline, with part already in trench and rest ready for moving into place.



A NINE-MILE HIGH-PRESSURE GAS MAIN

This pipeline, under construction for the Cambridge Division of the Eastern Gas Board, forms part of an integration scheme for which S & L have supplied more than 130 miles of pipe. The line is constructed for use at high pressures if required, being tested after completion at 450 lbs. per square inch hydraulic pressure, and followed by a seven-day 100 lbs. per square inch air pressure test. The S & L steel pipes are 12″ diameter, with ends bevelled for welding, and are protected externally with bitumen asbestos sheathing. Pipe-laying contractors : Biggs, Wall & Co. Ltd.

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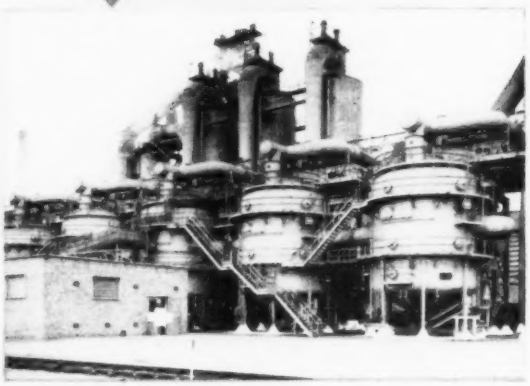
PLANT - by HEAD

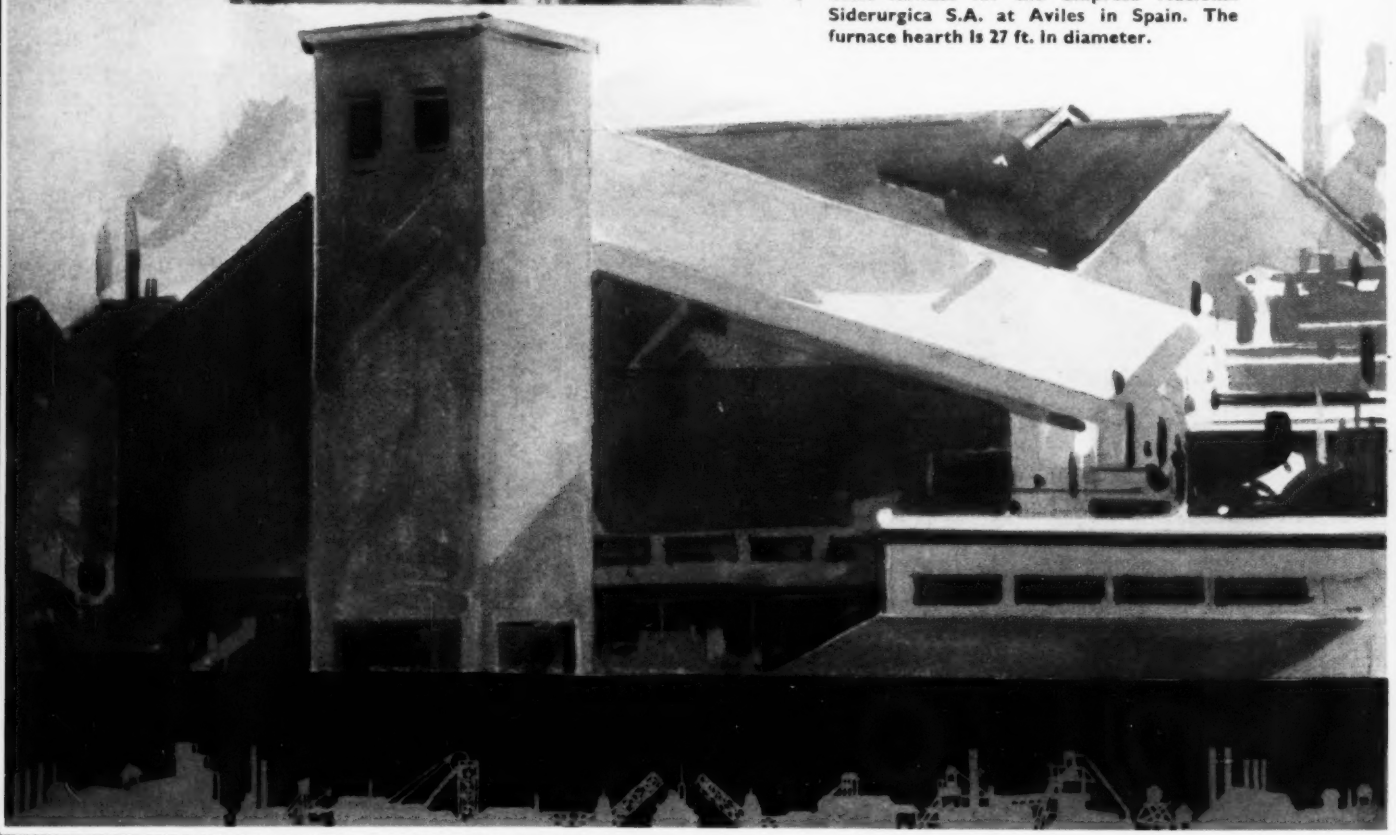
Complete plant and

A 180 tons capacity Hot Metal Mixer Car manufactured by Head Wrightson Teesdale Ltd. to the design of the Treadwell Co. of America in conjunction with the International Construction Co

Gas cleaning plant for the Appleby – Frodingham. Steel Co.

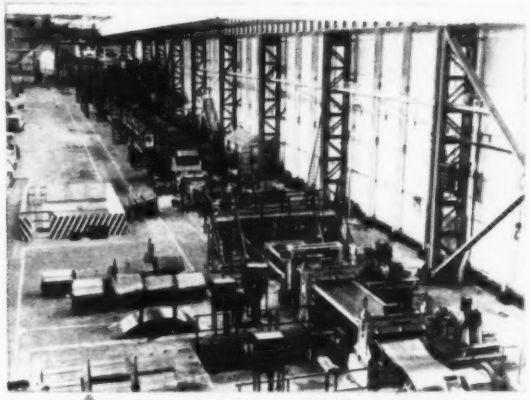


Blast furnace for the Empresa Nacional Siderurgica S.A. at Aviles in Spain. The furnace hearth is 27 ft. in diameter.

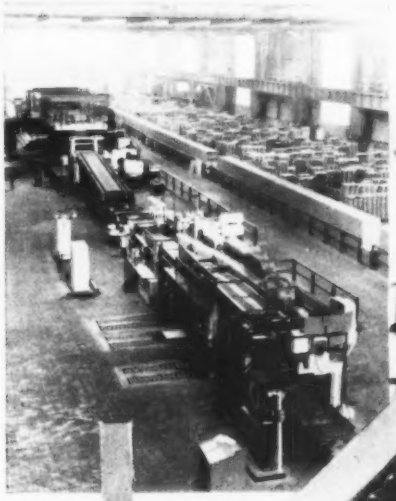


WRIGHTSON

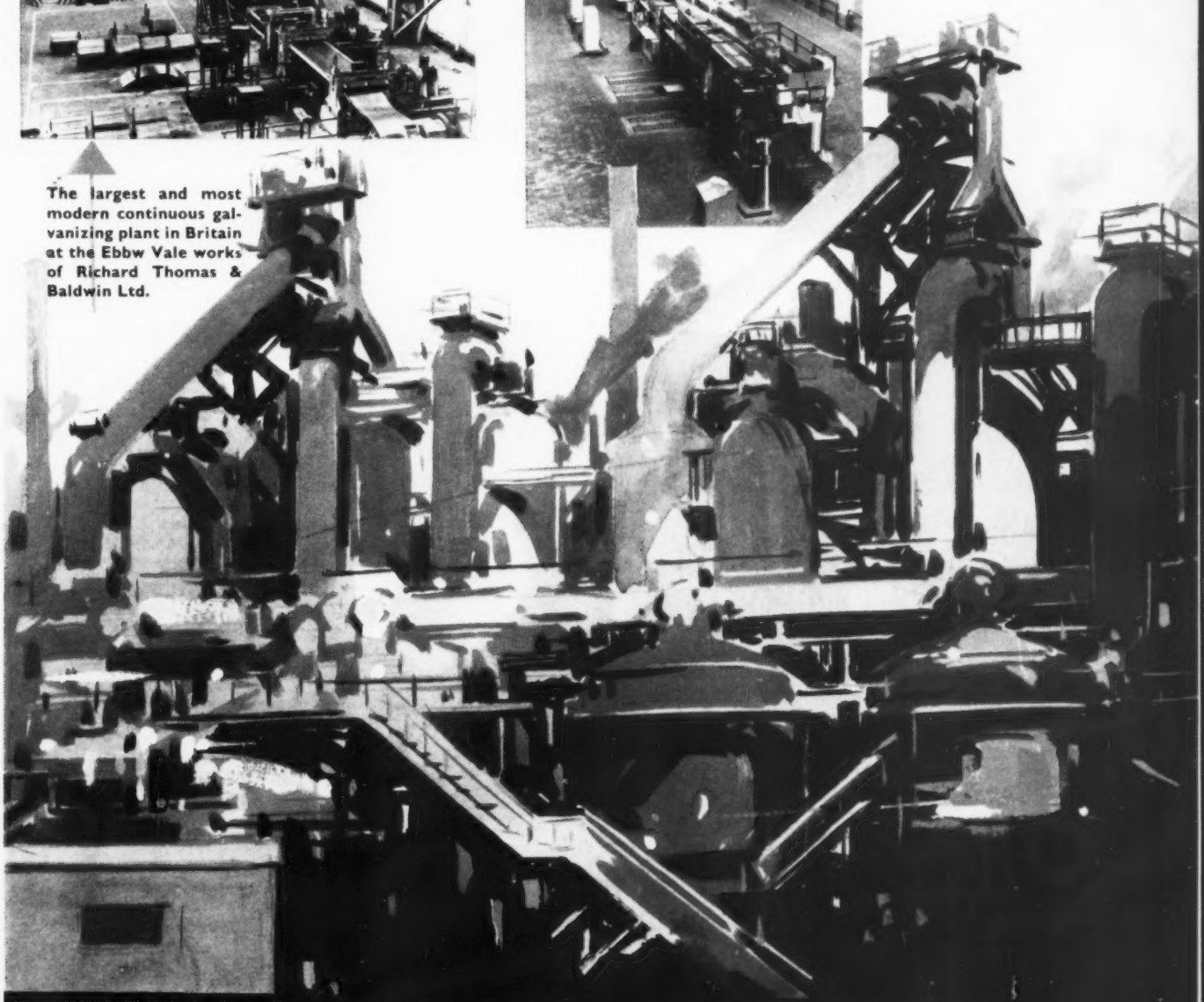
services for the steel industry



The largest and most modern continuous galvanizing plant in Britain at the Ebbw Vale works of Richard Thomas & Baldwin Ltd.



Electrolytic tinning line at the Velindre Works of the Steel Co. of Wales.



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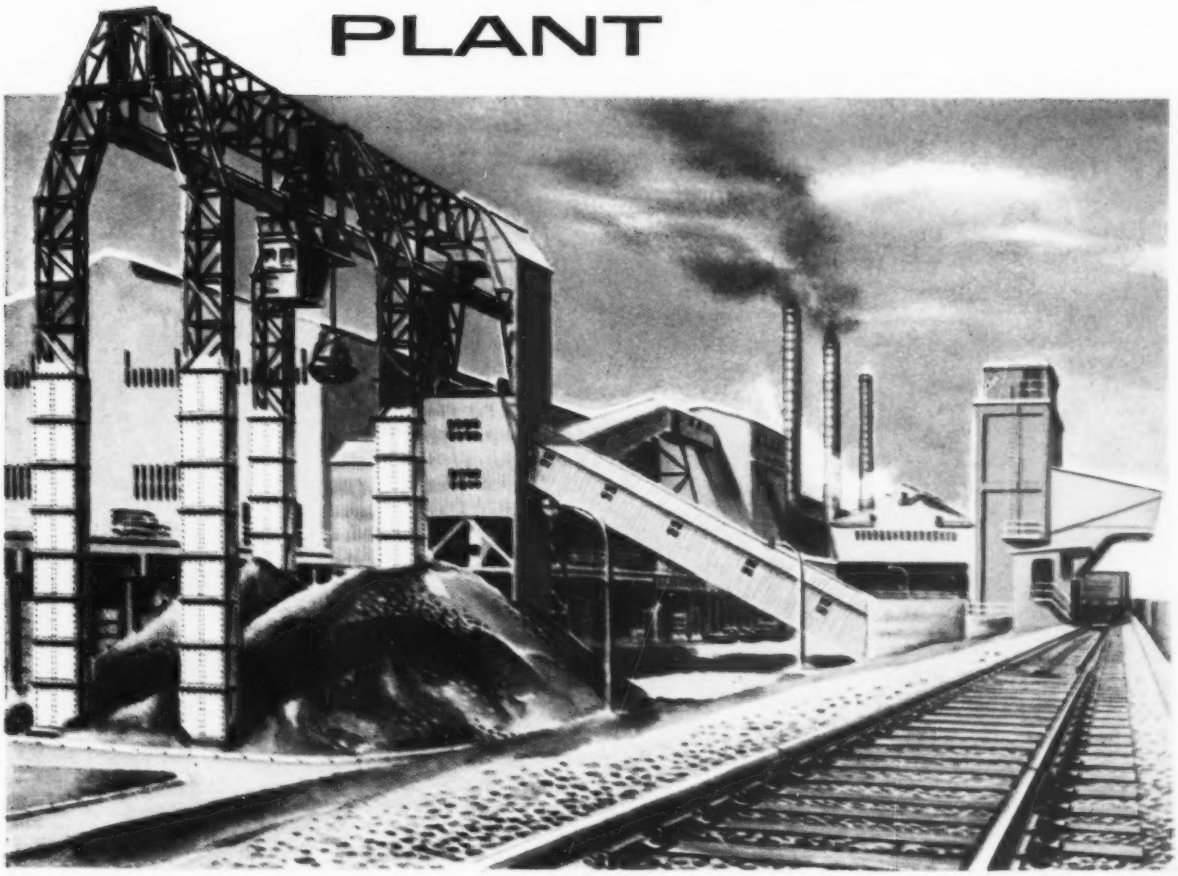

This raw material handling plant at Ravenscraig includes wagon marshalling, a dust trapping tippler, conveyors and a telpher, together with measuring box feeders and pan wagon control.

BY

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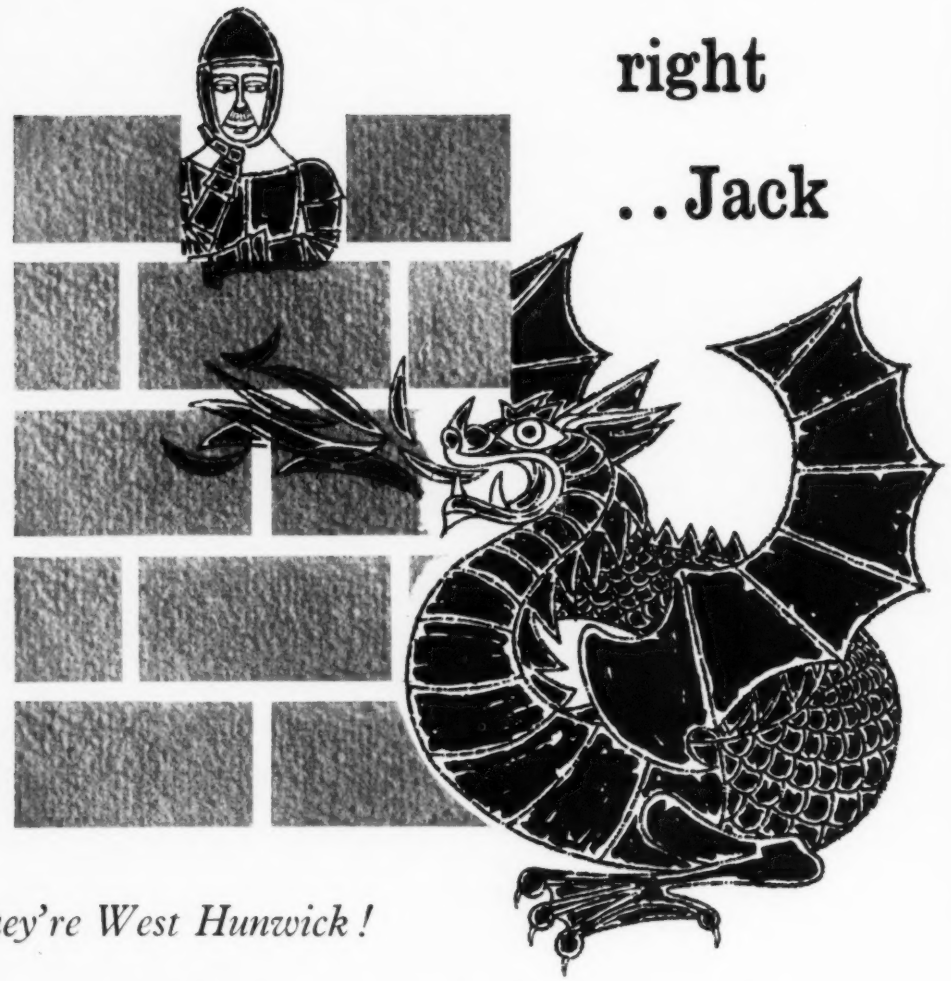
I'm all right .. Jack



they're West Hunwick !

Frustration to the insidious enemies thermal spalling, flame impingement, gouging at the skewbacks and all others which contribute to rapid roof wear. *On with the furnace campaign* protected by Hunnex *high duty* silica bricks in target areas and Hunwick *standard quality* silica bricks in areas where temperature and operating conditions are more normal.

HUNNEX *brand* — high duty quality. HUNWICK *brand* — standard quality.

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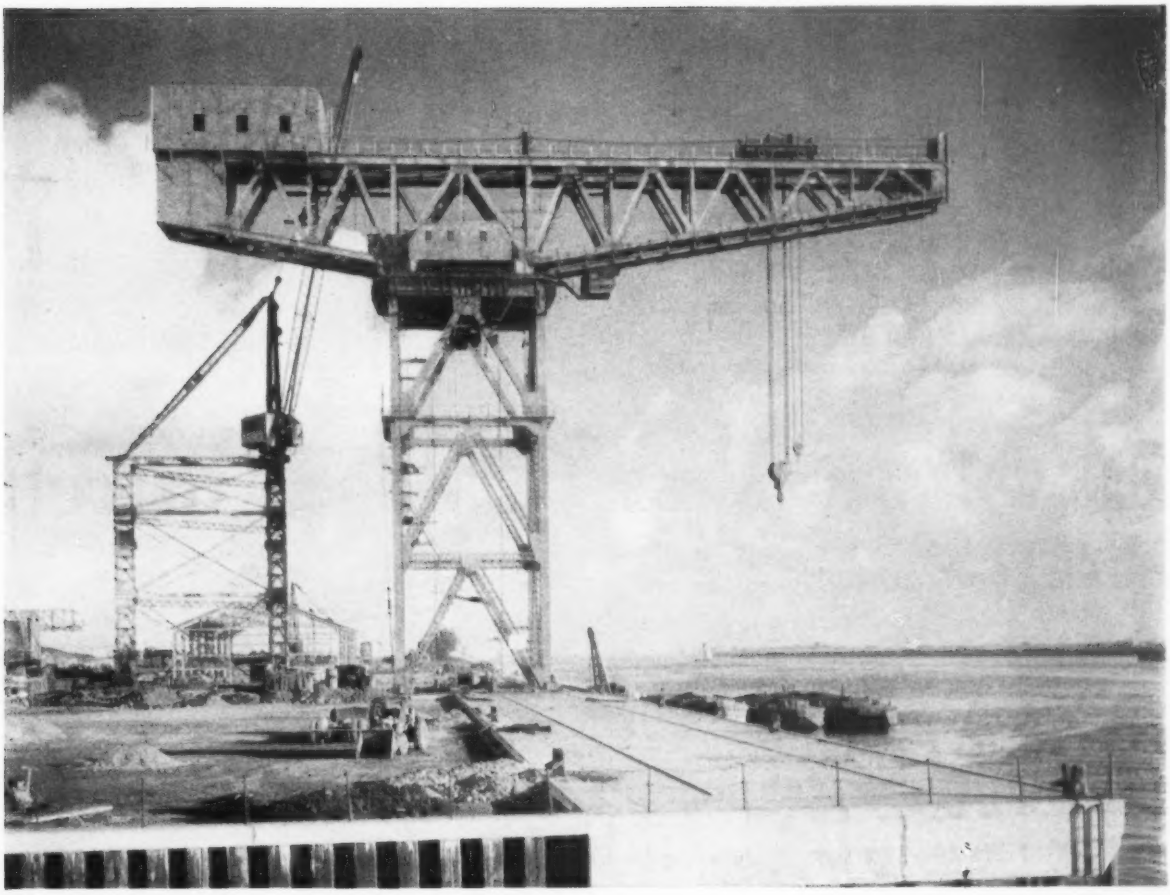
THE WEST HUNWICK SILICA & FIREBRICK COMPANY LTD., HUNWICK, CROOK, CO DURHAM TEL CROOK 200



Dockside Cranes

An ever-recurring sight, throughout the world, to those who go down to the sea in ships—a harbour crane by Arrol of Glasgow. This new crane at Belfast N. Ireland has a main hoist with a capacity of 200 tons. Auxiliary and whip hoists deal with loads up to 25 tons and 5 tons respectively. The 220 ft. long cantilever supported by a tower 40 ft. square can be rotated through a complete revolution in 10 minutes when carrying a full load of 200 tons.

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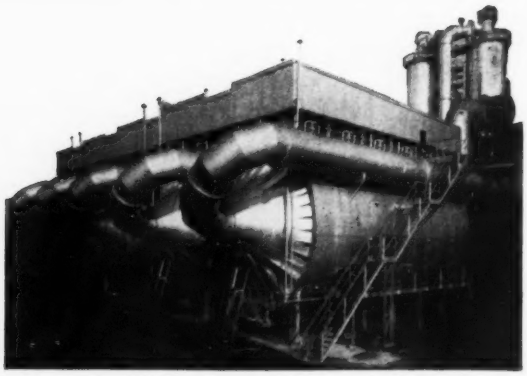

Photo Right: Close up of the five Precipitators installed by Lodge-Cottrell.

Photo Below: View looking towards 3 & 4 Blast Furnaces at Indian Iron and Steel Co's Works, Burnpur, India.

GAS CLEANING IN ASIA by Lodge-Cottrell

The competition for overseas contracts is as keen now as it has ever been. We are therefore glad to announce that a valuable contract to equip the Indian Iron and Steel Company's two new blast furnaces with four scrubber towers and five Electrofilters was completed on time before the end of 1958. The installation is capable of cleaning 15,000,000 cubic feet per hour of gas at S.T.P.

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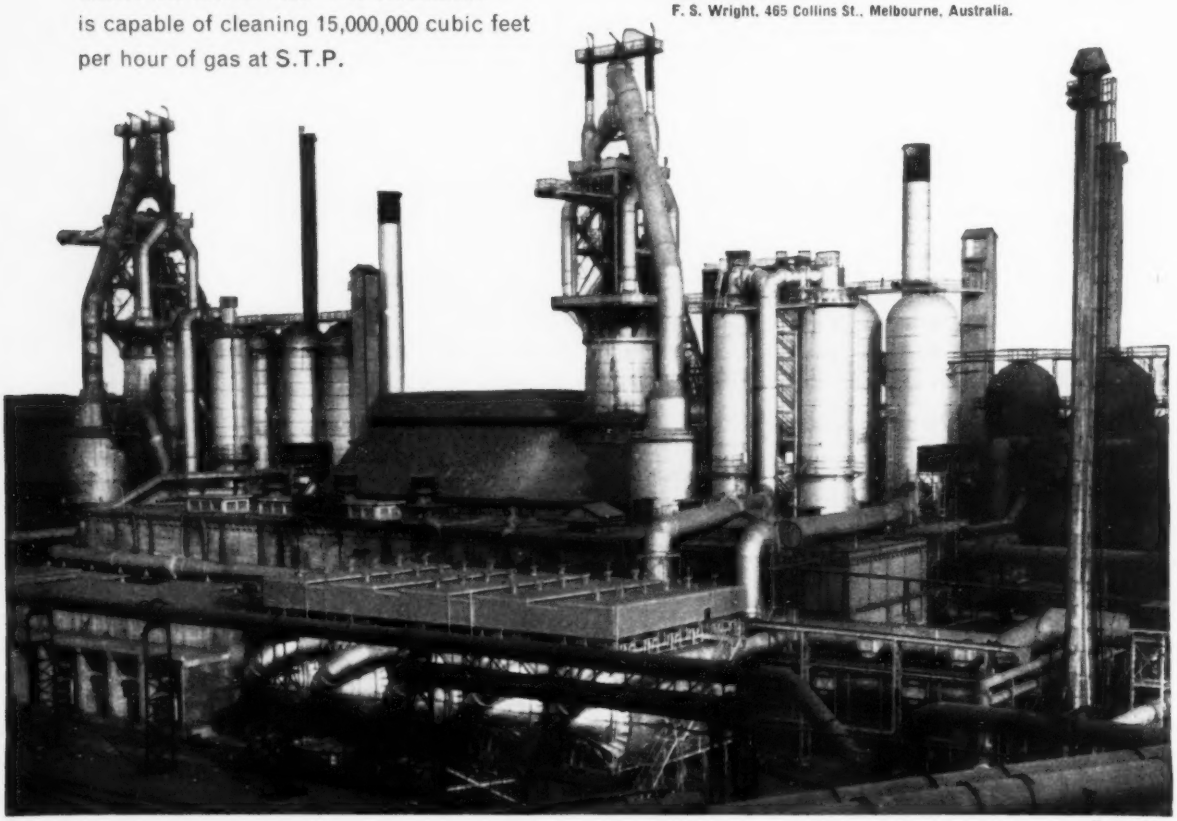
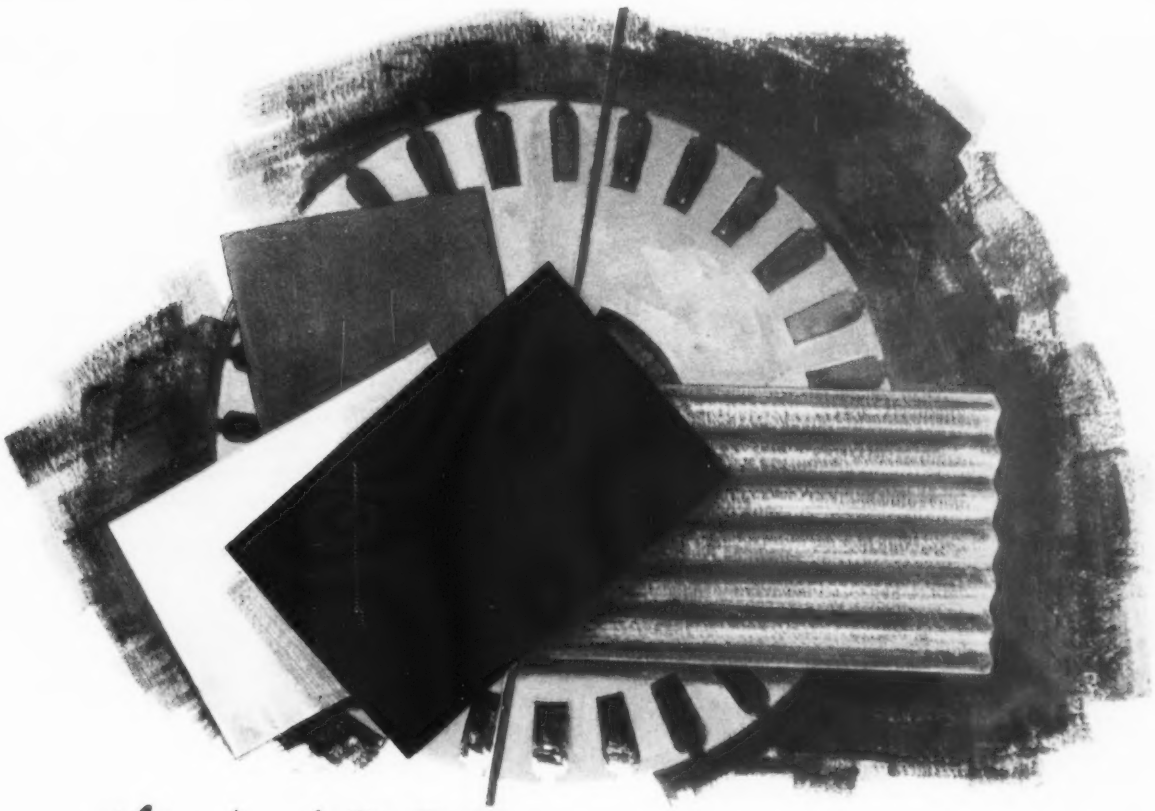


L.C.38.

When you hear of NEW DEVELOPMENTS–



think of R·T·B

The illustration, with some latitude, serves as a reminder of R T B tinplate, black sheets and specially coated sheets—together with a corrugated 'Speltafast' galvanized sheet and, behind them all, a large electrical lamination, made by R T B from one of their special steels.

Our history comprises a long sequence of developments which have proved of far-reaching importance to industry and to the general public. In steel making, in the production of tinplate, sheet steel and strip, in the manufacture of special steels and laminations for the electrical industry, and specially coated sheets, the name of R T B has always been associated with leadership.

The latest R T B development is the installation of the largest continuous-galvanizing unit in this country—for the production of 'Speltafast' galvanized strip and sheets.

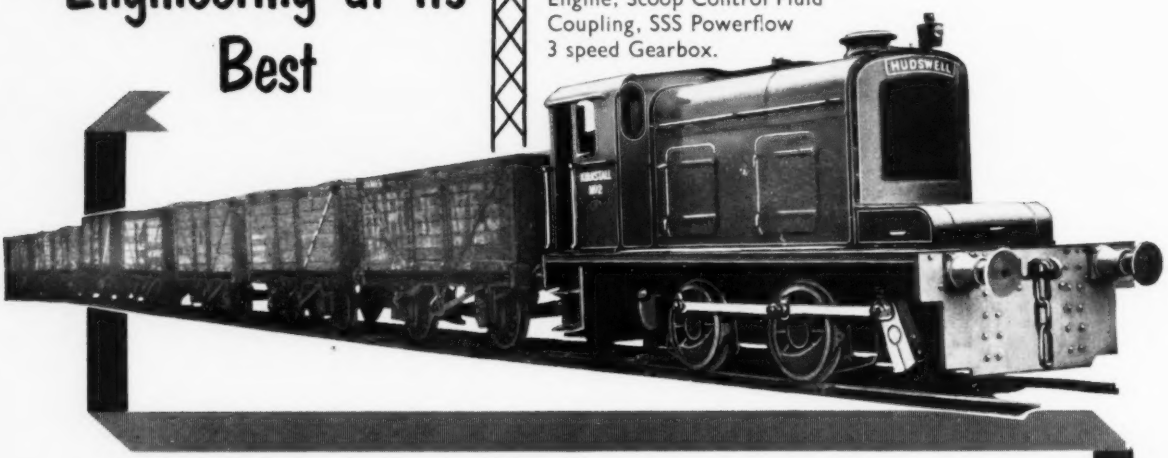
Richard Thomas & Baldwins Ltd.

R·T·B

British Locomotive Engineering at its Best

KIRKSTALL

153 B.H.P. Diesel Mechanical Locomotive. Fitted with Gardner 6 L.3 Diesel Engine, Scoop Control Fluid Coupling, SSS Powerflow 3 speed Gearbox.



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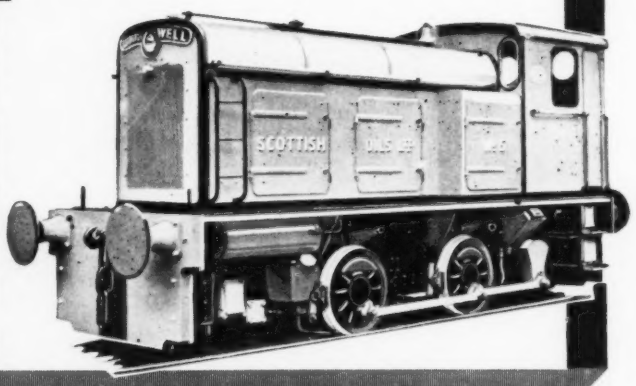
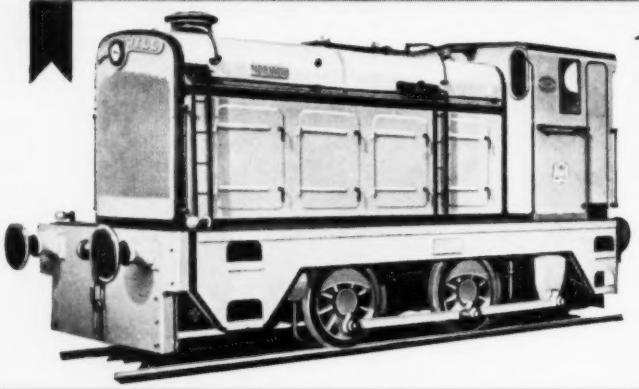
100 B.H.P. Diesel Mechanical Locomotive for Petroleum installations, fully flameproofed in accordance with Ministry of Fuel & Power regulations Group II Gases.

Fitted with National M4 A5 Diesel Engine, Scoop Control Fluid Coupling, SSS Powerflow 3 speed Gearbox.





PORT OF BRISTOL

204 B.H.P. Diesel Mechanical Locomotive. Fitted with 8.L.3 Gardner Diesel Engine, Scoop-control Fluid Coupling, SSS Powerflow 3 speed Gearbox.

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Heat Exchanger Lifting Girdle

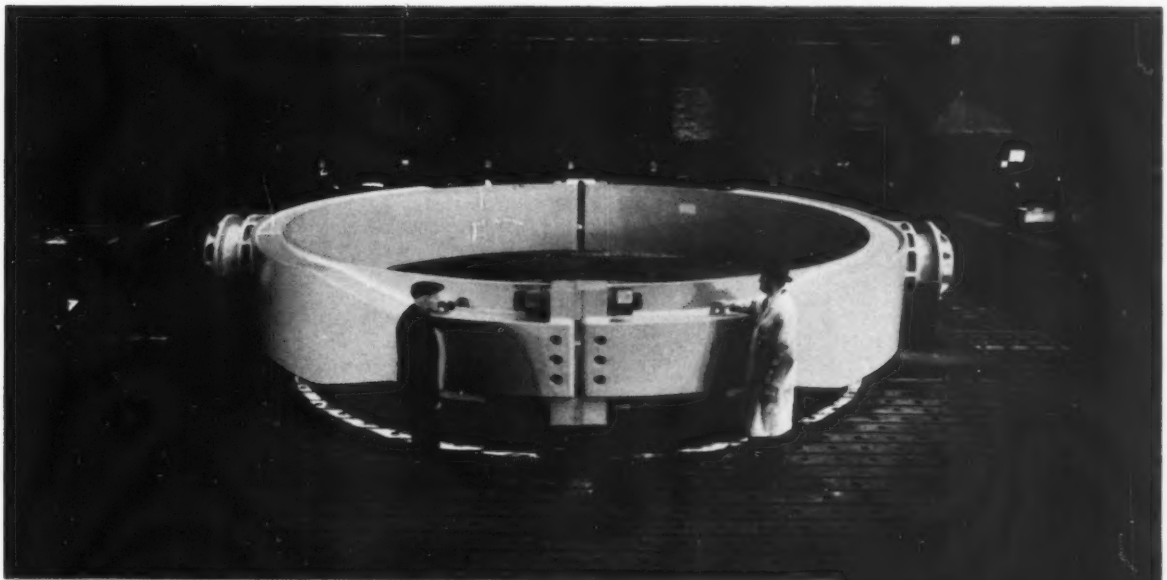
manufactured by Beardmore for Messrs. Babcock & Wilcox Ltd.

This unit, which was designed for a load of 400 tons,

will be used in the erection of the completed shells

of the Steam Raising Units at the Hinkley Point

500 M.V. Atomic Power Station.



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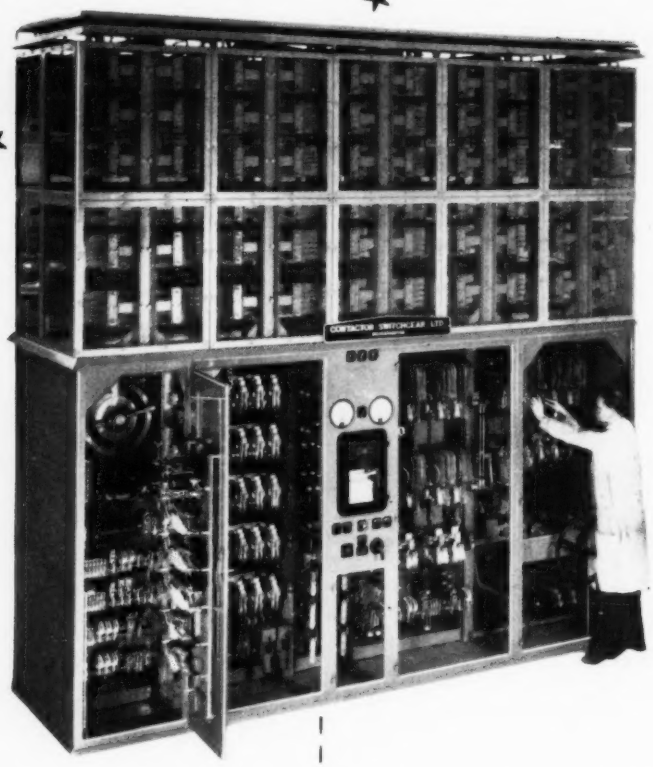
Control Gear for Steelworks Plant



The photograph shows a 2,300 H.P. 600 volts D.C. Shunt (Stability Compounded) motor control panel incorporating a motorised preset shunt field regulator, 'inch forward', 'inch reverse' features and emergency sustained dynamic braking for a "Cross Country" steel rod mill.

Contactor Switchgear Limited manufacture automatic electric control gear (up to 6,600v A.C. and 650v. D.C.) for Power Station Auxiliaries, Steel Works, Water Works, Rolling Mills, Sewage Works, Chemical Plants, Gas Works and Cement Works, including Cranes, Electric Furnaces, Machine Tools, Fans and Pumps.

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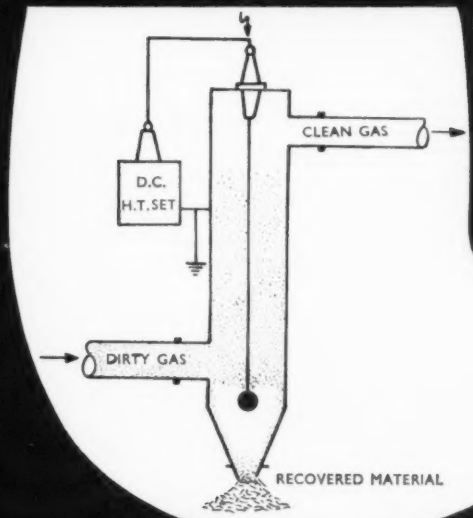

You can't afford smoke nowadays – it's bad for you and it's bad for other people too. For clean air you need the very best in electro-precipitation. That is what our extensive research and development resources, backed by unrivalled experience, can give you. Pollution from the chimneys of power stations, iron and steelworks, chemical plants and other industrial plants all over the world has been cut to a minimum by our high-efficiency electro-precipitation. It's time your chimneys, too, gave up smoking!

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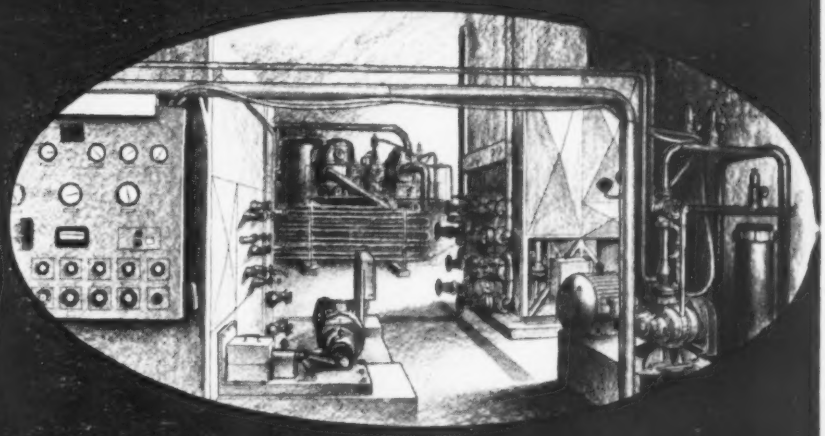

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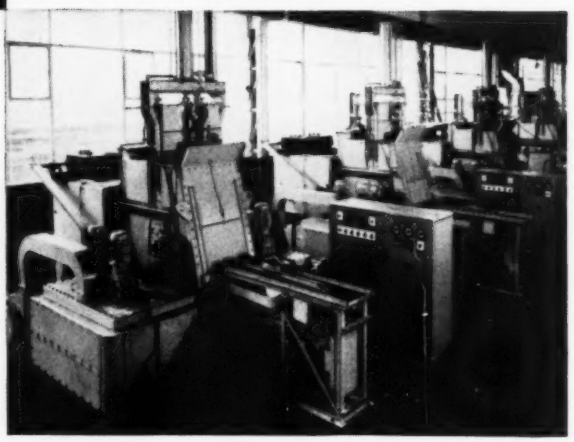
An installation of pit type furnaces with separate cooling chambers and oil and water quench tanks for carburising and hardening motor gear box parts.

EFCO furnaces



Humber Ltd chose Efco-Lindberg horizontal closed quench furnaces for carburising and carbonitriding gear components. The furnaces are electrically heated with Corrtherm elements.

Austin, Ford, Humber, and other leading motor manufacturers chose Efco Furnaces for hardening, gas carburising or carbonitriding gear components.

When you decide on Efco furnaces you may pick from the best of the World's current designs. For carburising and carbonitriding there are both vertical and horizontal closed quench furnaces, and vertical furnaces with separate cooling chambers. For hardening there are many continuous designs including shaker hearth, roller hearth and pusher furnaces.

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ADVERTISEMENT

Electrical Aids in Industry *Data Sheet* **No. 6**

Lighting -1

Good lighting affects productivity in three ways, (1) by directly increasing the speed of working and reducing errors and wastage, (2) by improving overall factory efficiency through better supervision and housekeeping, (3) by providing better working conditions, thus improving labour relations and avoiding frequent changes of workpeople.

It is not possible to judge by the eye alone whether the lighting in any factory is good enough to serve these purposes because the eye has a tremendous range of adaptation (vision of some kind is possible within an illumination range of 1,000,000 to 1) and is hence an unreliable measuring instrument. Severe mental and eye strain or unconscious slackening of working speed may occur under lighting which *appears* to be adequate.

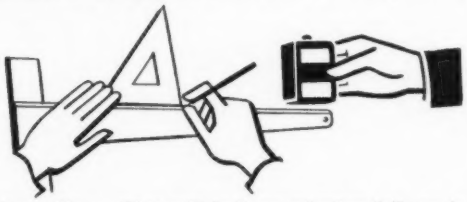
The only reliable way to appraise factory lighting is to conduct a lighting survey using a lightmeter, an inexpensive instrument which measures the actual illumination available. These figures can then be compared with official recommended values for the various tasks.

Lighting Survey

A methodically conducted lighting survey is the first step towards achieving good productive lighting. The average artificial illumination at working height should first be measured. This requires a number of readings at various positions relative to the lighting fittings, particularly beneath and between fittings and by the wall. The average of the readings should then be compared with the illumination values recommended by the Illuminating Engineering Society. The following is a general guide to illumination requirements.

NATURE OF WORK, PROCESS OR MATERIAL	ILLUMINATION LUMENS/SQ.FT.
Rough or routine work. Large detail. Medium to light material of good contrast.	7
As above, but work rather more skilled or critical.	10
Ordinary work usually involving workers' inspection. Medium detail and contrast.	15
Fairly critical work, fairly small detail or poor contrast.	20
Skilled work, small detail or dark material.	30
Fine or critical work, very small detail, very poor contrast or very dark material.	50
Very fine exacting work.	100
Minute work.	200

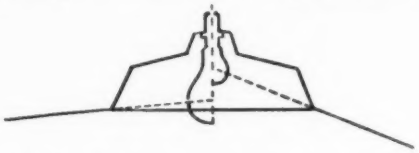
In addition, readings should be taken at selected working points with the lightmeter so placed that it measures the light on the work while the operative



is working. This will indicate whether full use is being made of the light or whether shadow is obscuring part of it.

Glare

Any direct light on the eye tends to reduce its sensitivity—thus reducing the power to see. Increasing the intensity of the light source may



therefore not improve matters unless care is taken to avoid glare either by correct positioning or by the use of correctly matched reflectors and lamps.

Walls and Ceilings

Certain surfaces and certain colours absorb light and therefore do not make the best of a light source; others reflect light and, so to speak, feed back on to the work a portion of the lighting which would otherwise be lost. Bright walls, moreover, have a good psychological effect which makes for contented —and therefore productive—operatives.

Shadows

Unnecessary shadows may seriously slow down work and also cause accidents. Lightmeter readings should always be taken under conditions exactly similar to those obtaining while work is going on. The operative himself may mask his work, an overhead crane or a heavily loaded conveyor belt may periodically obscure a light fitting, or a dust-laden atmosphere may reduce the designed lighting values.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone : TEMple Bar 9434.

Excellent reference books are available on electricity and productivity (8/6 each or 9 - post free)—"Lighting in Industry" is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity including one on industrial lighting. Ask for a catalogue.

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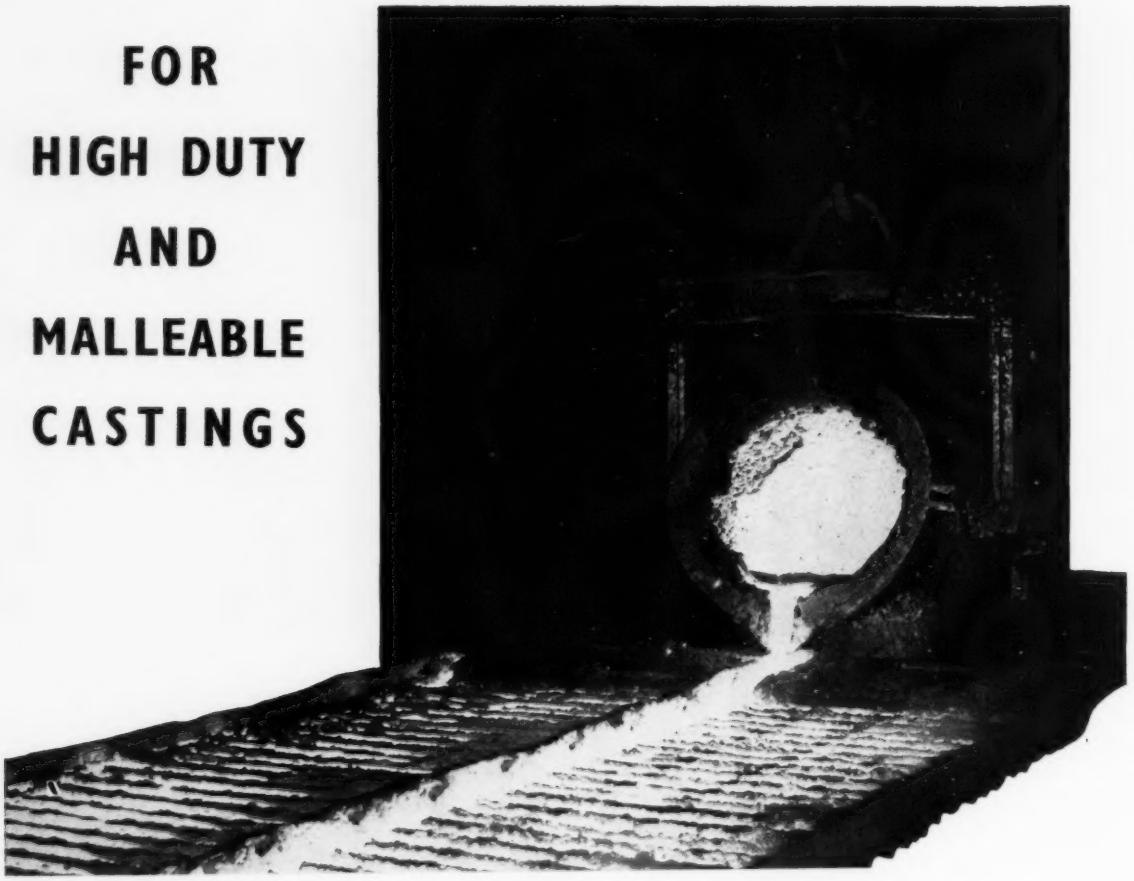

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SULPHUR%	0·06	0·07	0·08	0·05	0·08	0·07	0·06
PHOSPHORUS%	0·6–0·7	0·6–0·7	0·6–0·7	0·4–0·5	0·25	0·25	0·25
MANGANESE%	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5	0·8–1·5
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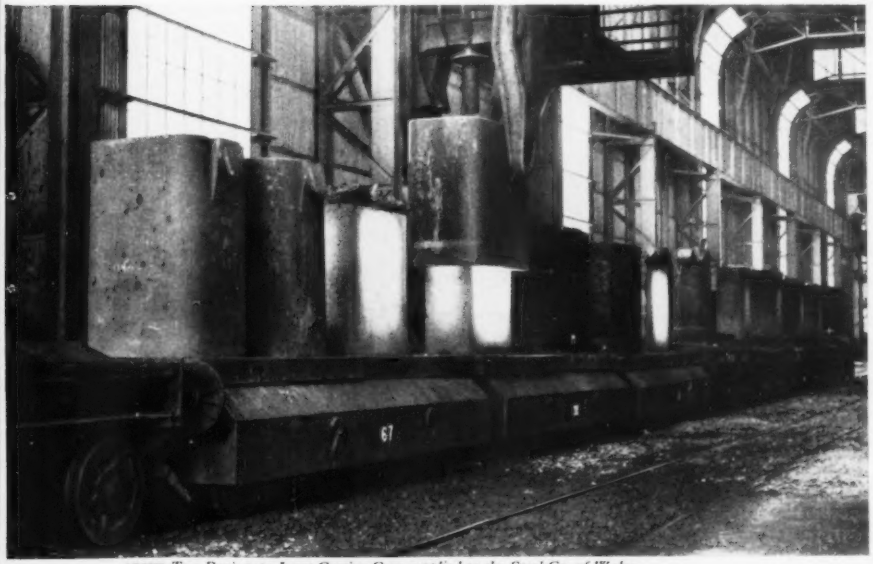
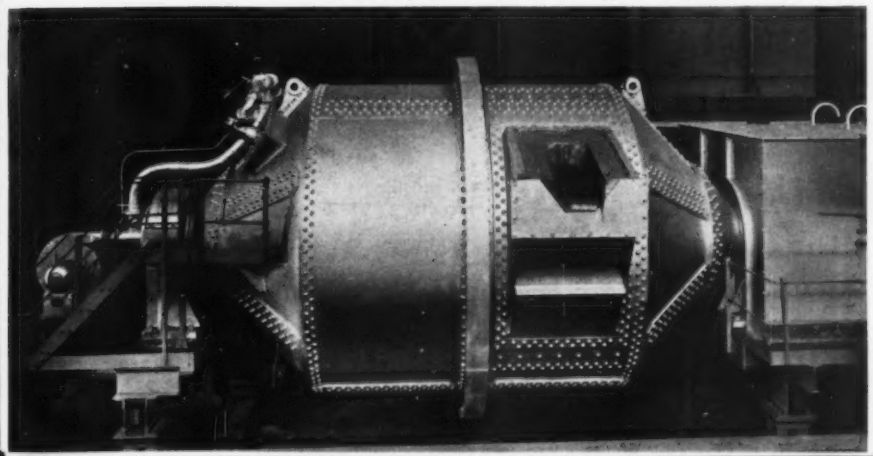
RIGHT *275 ton capacity Steel Casting Ladles and Ingot Casting Cars at John Summers and Sons Limited.*



ABOVE *Two Bogie type Ingot Casting Cars supplied to the Steel Co. of Wales.*

BELOW *A 150 ton Hot Metal Receiver supplied to Brymbo Steel Works Limited.*



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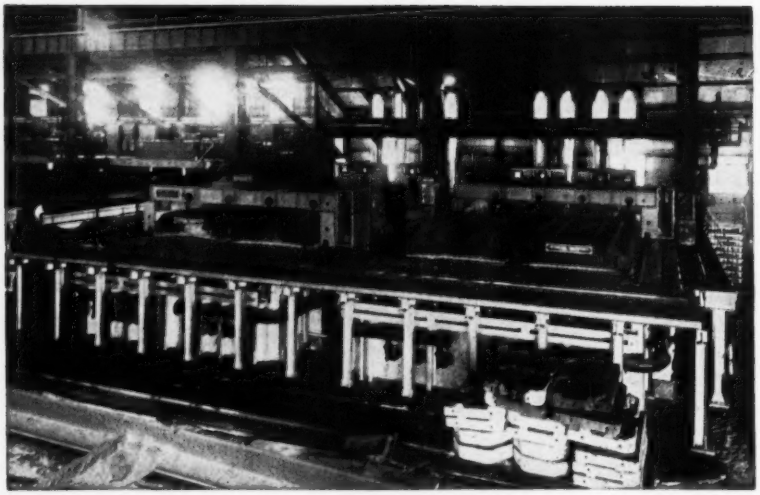

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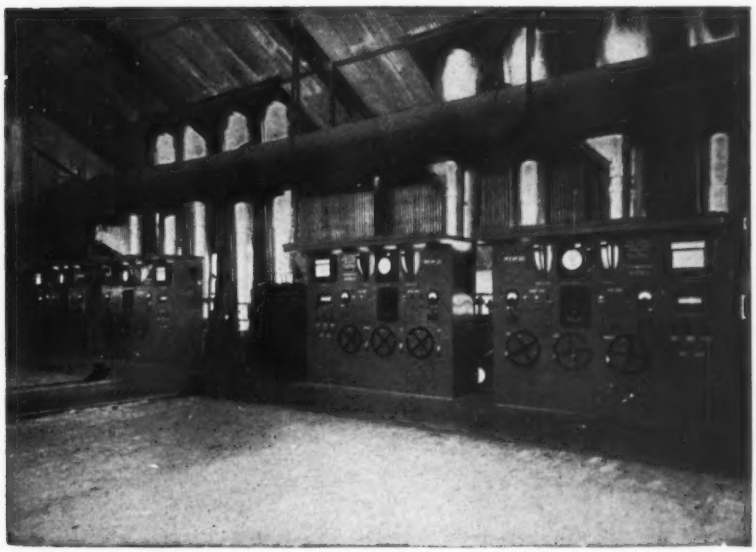

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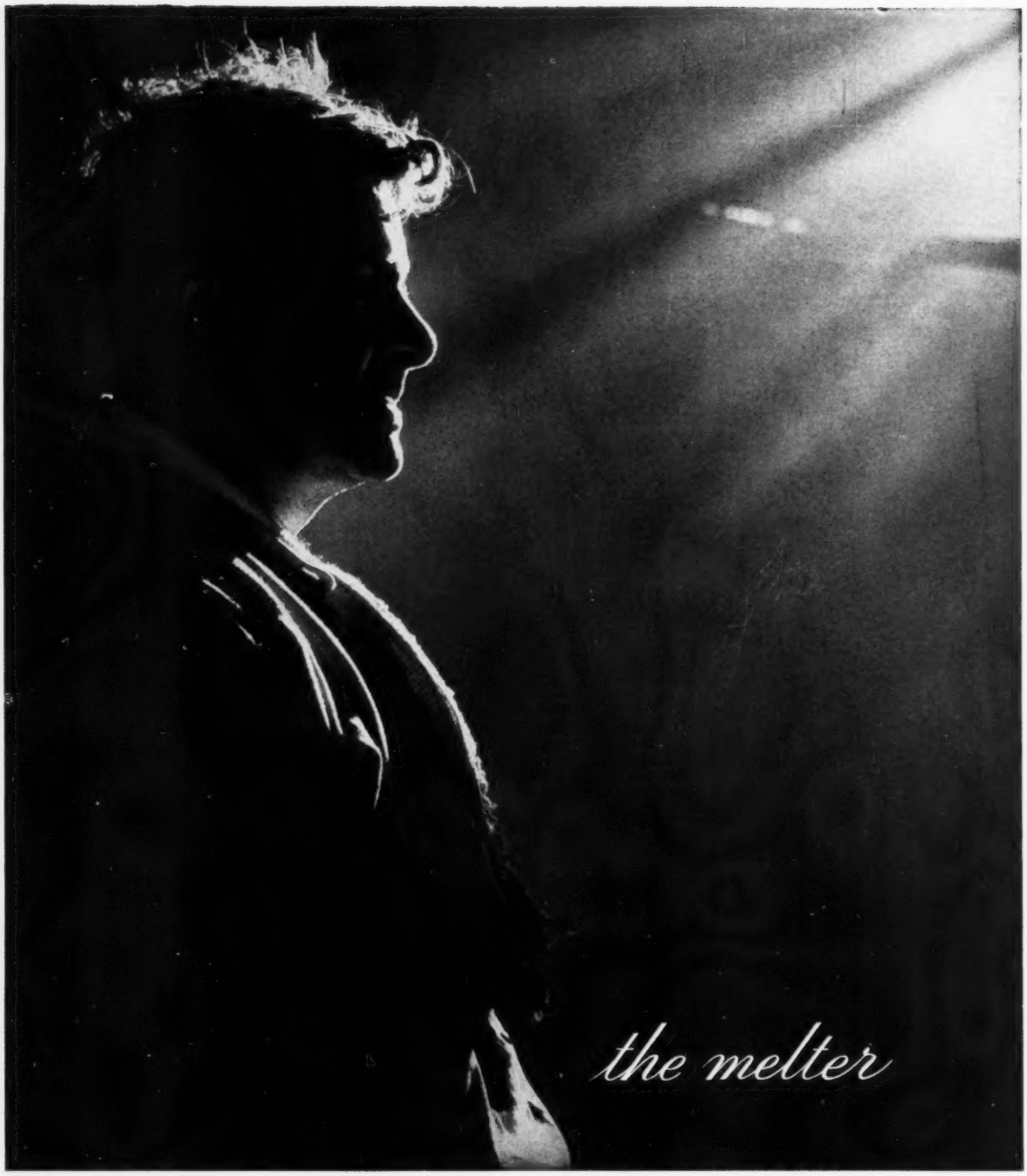

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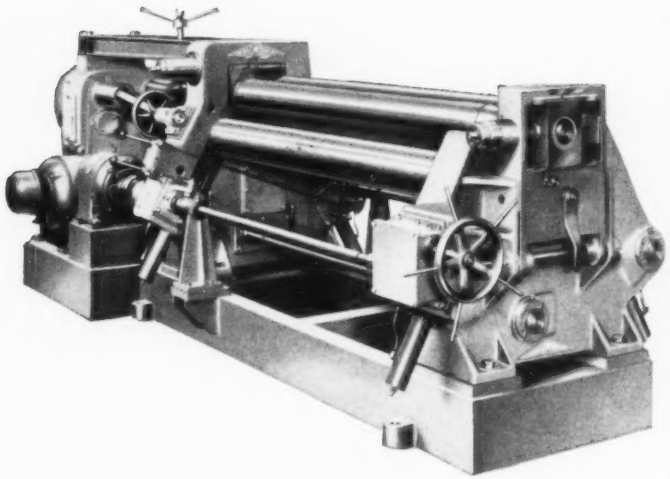

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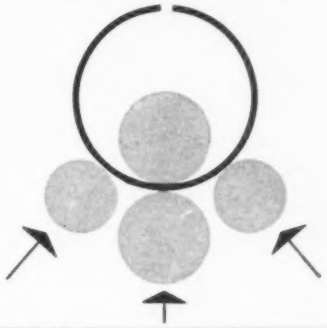

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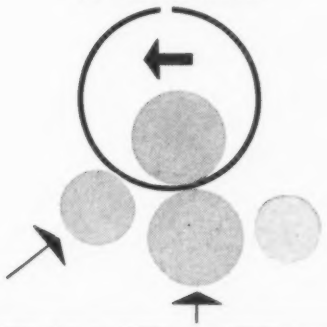

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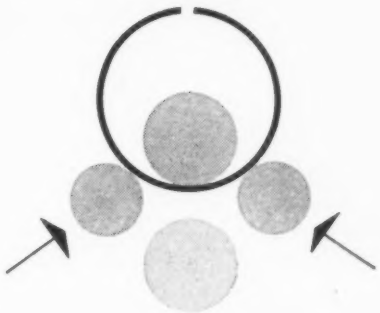

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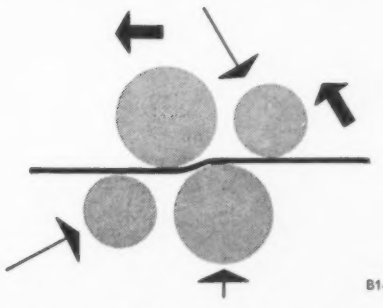

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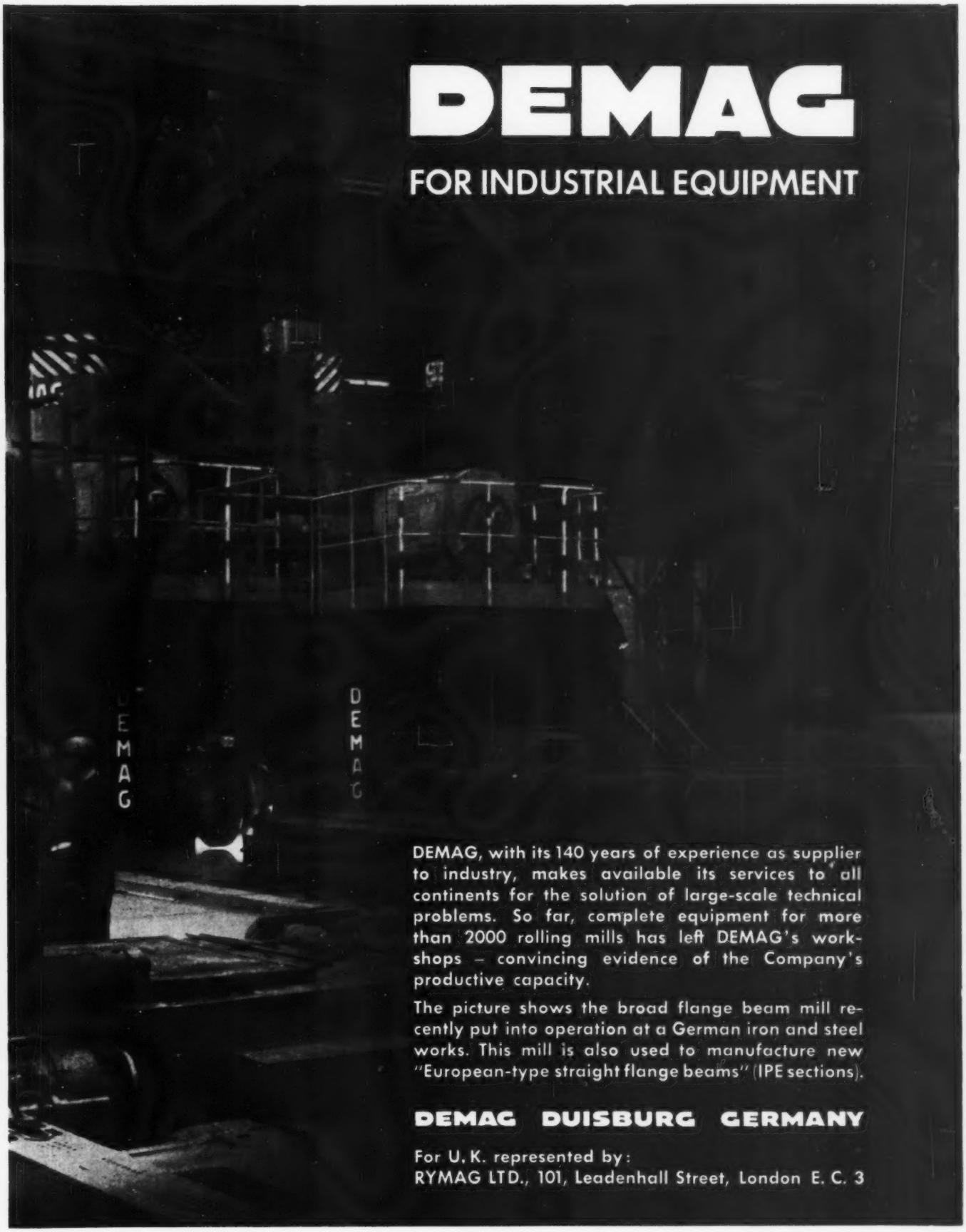

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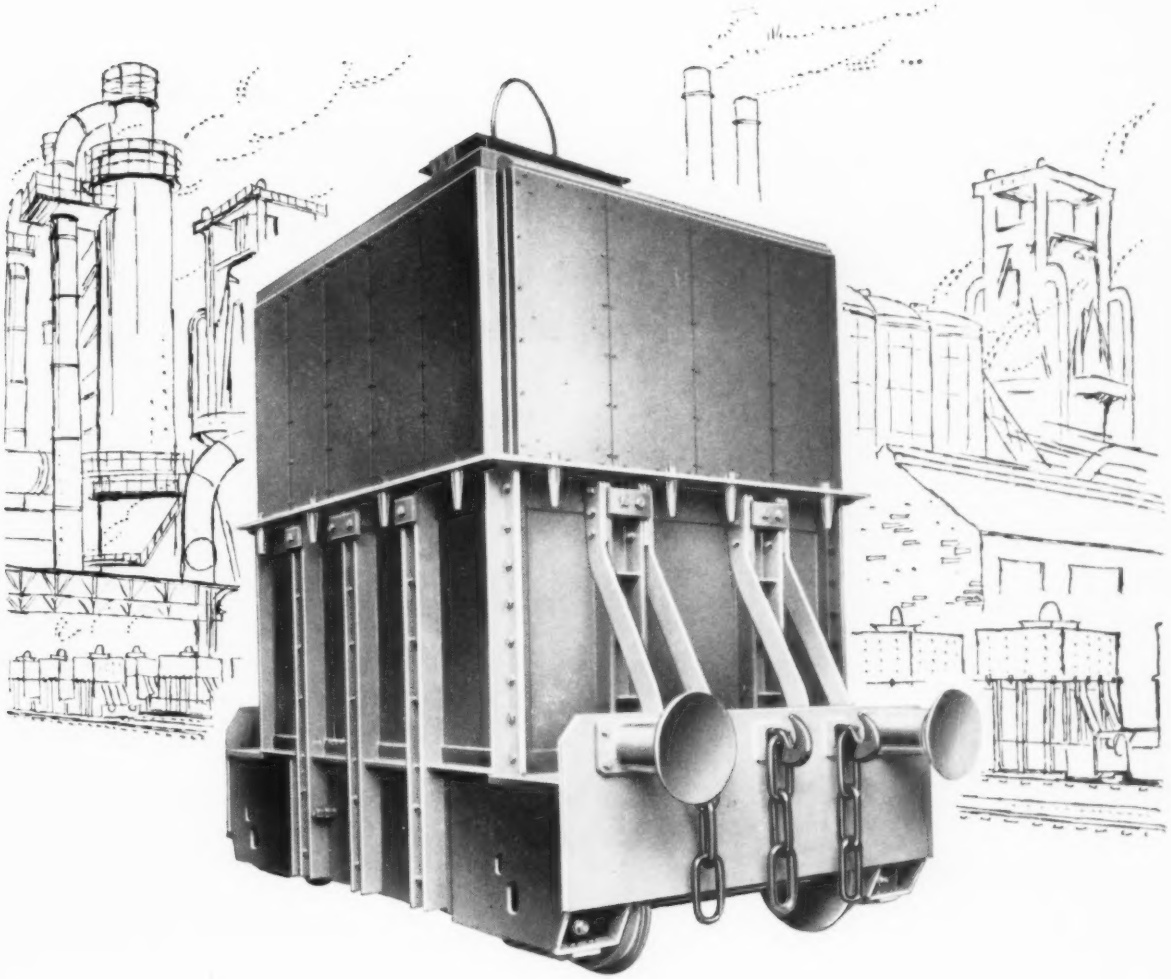

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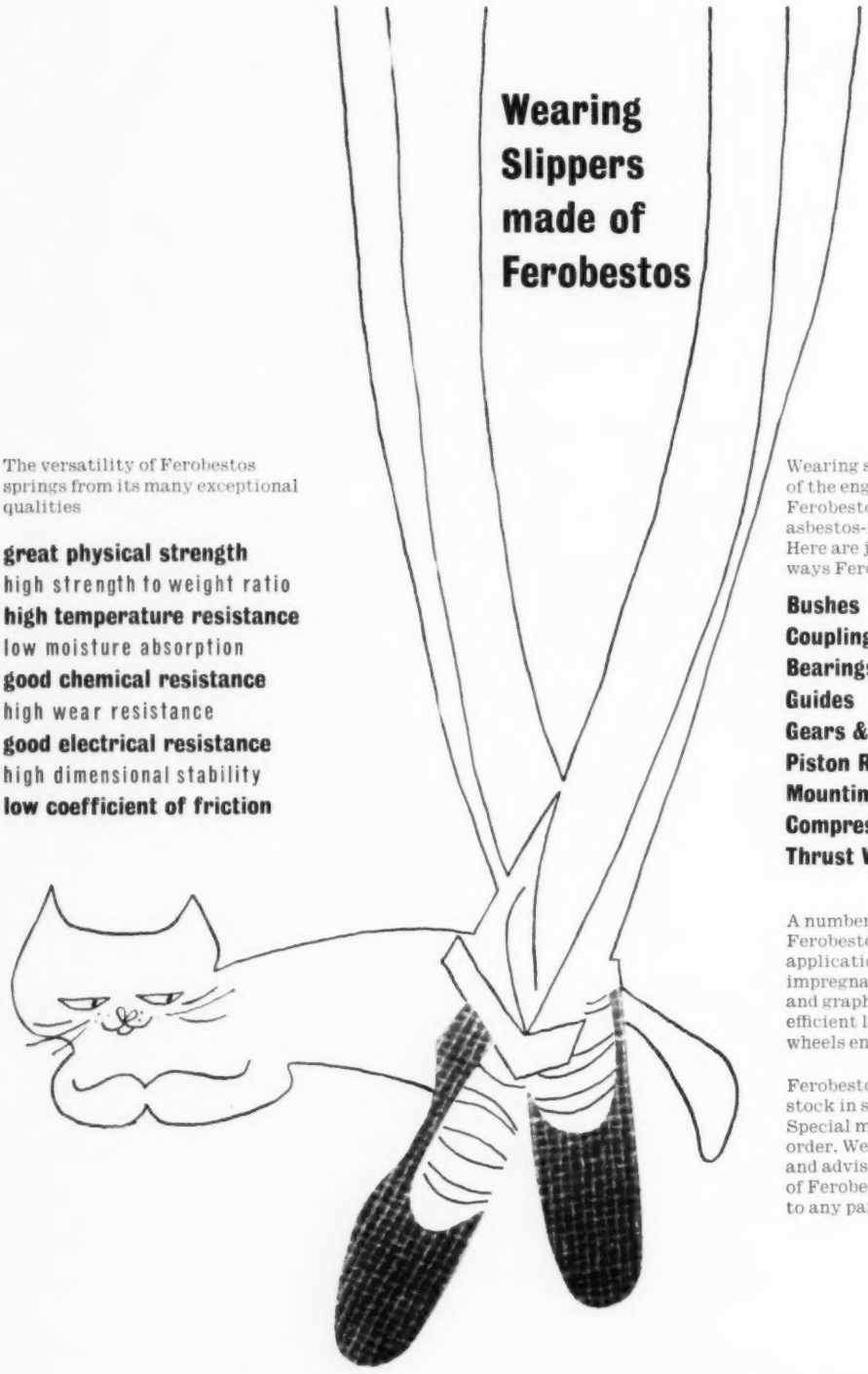

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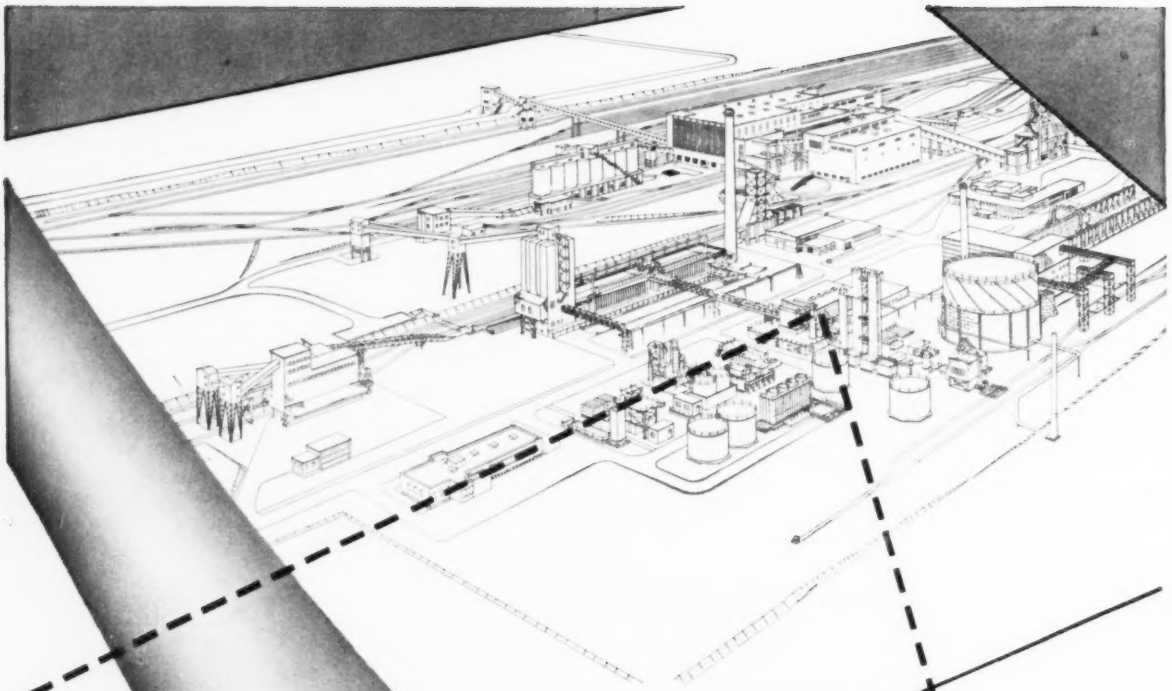

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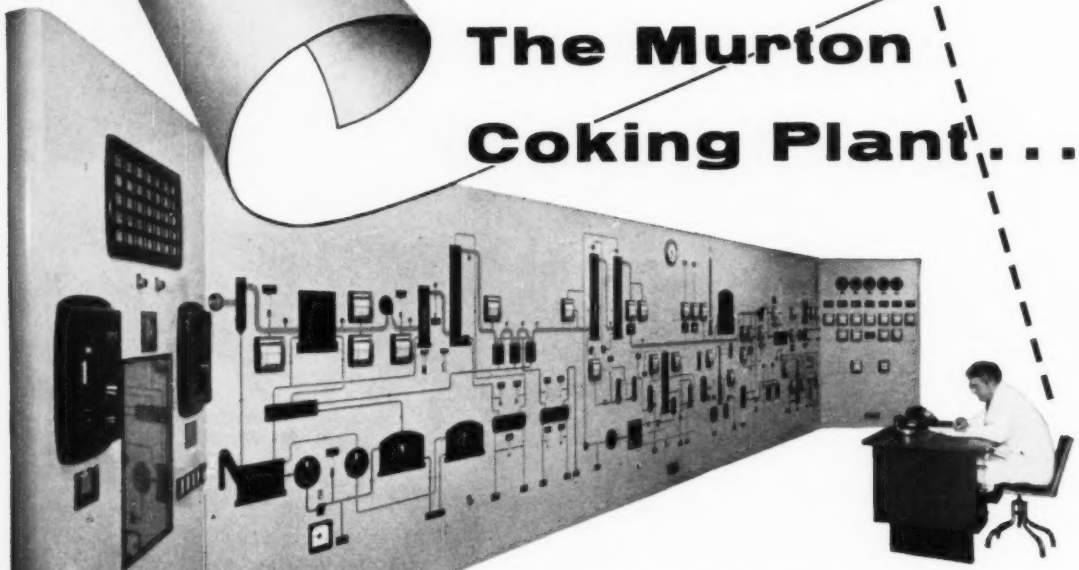

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SEPTEMBER 1959 Volume 193 Part 1

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Another

Wellman

Complete Steelworks Installation

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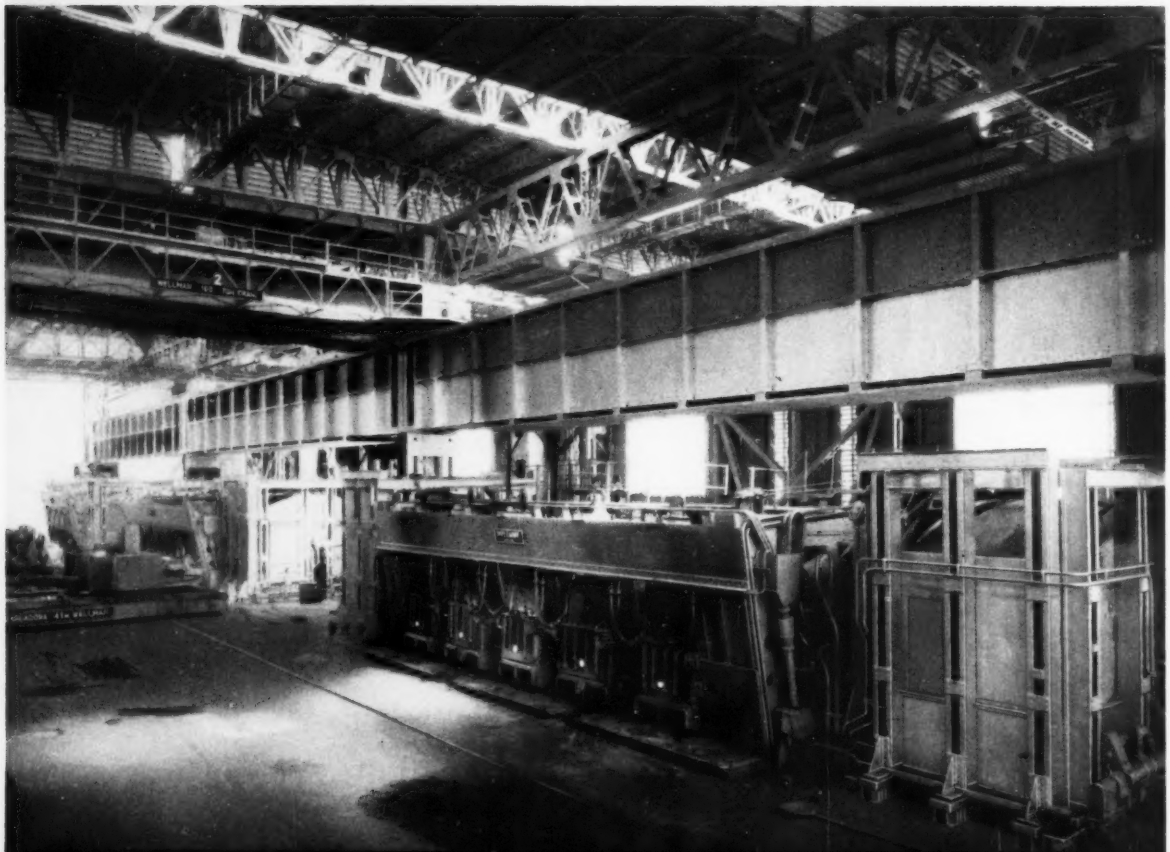

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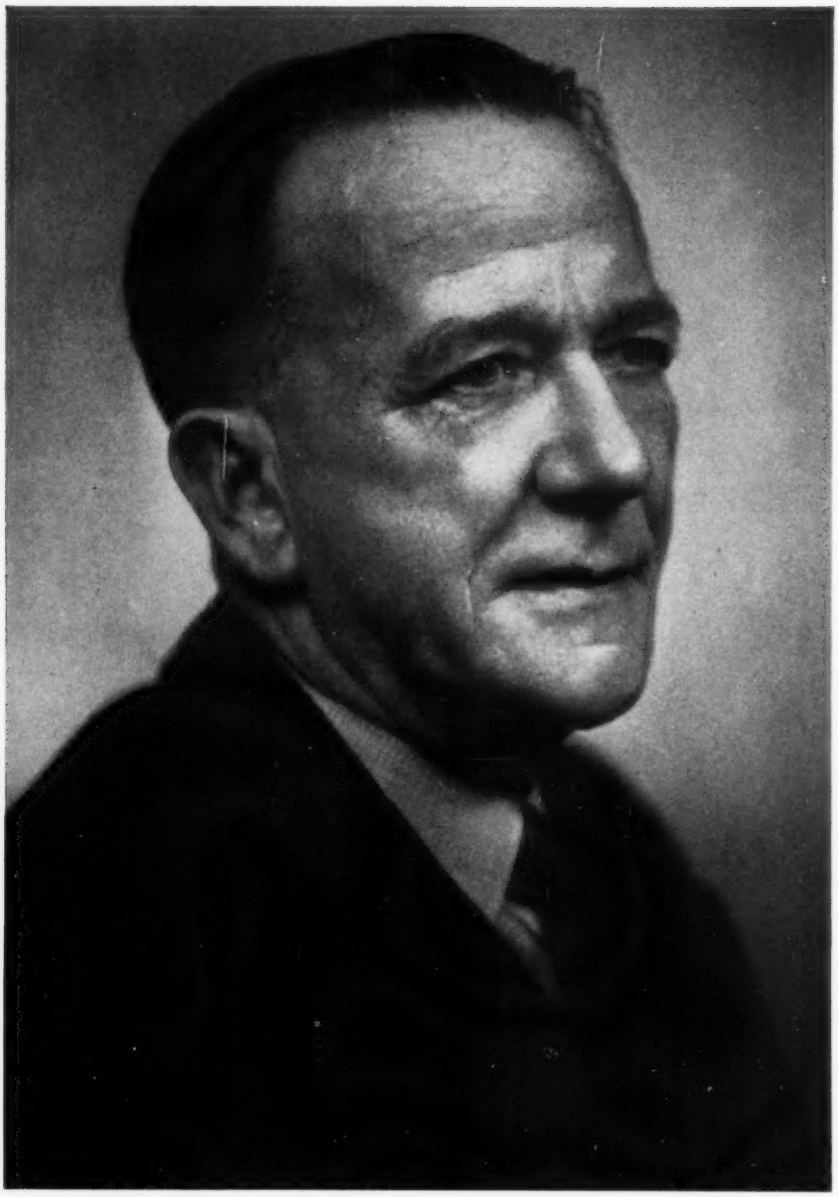
ROBERT HIGGINS trained at the Royal Technical College, Glasgow, from 1913 to 1921, interrupting his studies to serve with the Royal Engineers in the first world war. In 1921 he was awarded an associateship of the college, and in the following year he graduated from the University of Glasgow. He gained practical engineering experience at Wm Beardmore Ltd, Glasgow, and at Colvilles Ltd, Motherwell, and was a Greenock Research Scholar and Carnegie Scholar carrying out research work at Glasgow Royal Technical College for which he was awarded his degree of Ph.D. in 1926.

Dr Higgins then joined the metallurgy department at Glasgow until his appointment in 1930 as senior lecturer in metallurgy at the University College of Swansea. He later became assistant professor of metallurgy at Swansea, where he was particularly concerned with research problems connected with the steel industry in South Wales and worked on several research committees.

In 1947 Professor Higgins was awarded one of the first Nuffield Travelling Fellowships to study the metallurgical industries in Canada, and in 1953 he spent some time in Rhodesia studying smelting on the copperbelt. In the same year he was awarded the O.B.E.

Professor Higgins has been a member of The Institute of Metals for many years and is a Fellow of The Institute of Metallurgists. He joined The Iron and Steel Institute in 1923 and in 1958–59, as president of the Swansea and District Metallurgical Society, he served as an Honorary Member of the Council of the Institute.



R. Higgins, O.B.E., Ph.D., A.R.T.C., F.I.M.
Honorary Member of Council, 1958–59

Abraham Darby and the beginnings of the coke-iron industry

H. R. Schubert

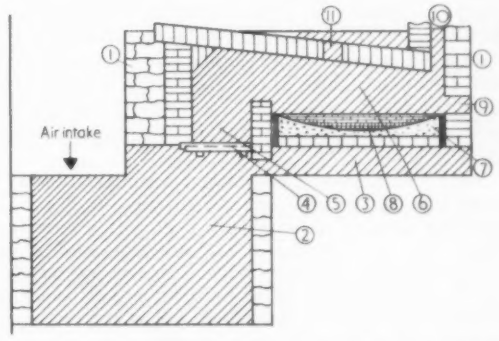
ABRAHAM DARBY, who is credited with the first successful production of iron using coke instead of charcoal as a fuel, was born in 1678, the son of John Darby, at Wren's Nest, to the west of Dudley, Worcestershire.[1] John Darby is first referred to in a lease of 10 December 1649, by which several parcels of land in the Old Park in the parishes of Dudley and Sedgley were demised to him for a term of twenty-one years at a yearly rent of £30. In the lease, Darby is described as a locksmith of Sedgley, Staffordshire, but the document shows him to be a man who combined agriculture with craftsmanship.[2]

John Darby, who was a member of the Society of Friends, put his son as an apprentice to a trade at Birmingham, where there was a large community of Friends. An active member of the society, Jonathan Freeth, a malt-mill maker, became Abraham's master. During his training, Abraham conscientiously attended the meetings of the Friends, and their works became, and remained, an essential part of his life.

After the completion of his apprenticeship in September 1699, Abraham Darby married Mary Sergeant (whose parents were bleachers of linen yarn), at a meeting of Friends at Dudley. Subsequently he set up business at Baptist Mills in Bristol as a maker of malt mills.

In the following year, a complete change in Darby's business activity took place. It was connected with a new wave of increased production in the copper and brass industry that began towards the end of the seventeenth century. After the restoration of Charles II, as a reaction against the Cromwellian Puritanism there was a nation-wide spread of fashion and luxury, and an increasing demand for goods of an artistic nature. For the manufacture of such articles brass and copper were more suitable than iron. Around 1700, however, the art of making brass was not fully understood in England, and this was the main obstacle to the setting up of brass factories. The only solution was to secure skilled workmen from abroad, who would be able to teach the English the art of making brass. This course was followed by Abraham Darby, who added brass manufacture to his original business in Bristol, jointly with Edward Lloyd, Benjamin Cool, Arthur Thomas, and John Andrew. Operations started in 1702, under the name of the 'Bristol Brass Wire Company'. The new establishment developed rapidly because of the extremely advantageous position of Bristol. The city was still an important port at this time, and large home markets were provided by the pin trade of Gloucester and Bristol, and still more by the growing manufacture of other metal goods, the raw material for which was supplied by the Bristol company for most of the eighteenth century.[3] The moving spirit of the company was Nehemiah Champion, a Quaker, who also joined the partners.[4]

To make brass, it was necessary in those days to blend copper with calamine, the ore of zinc. This was done in a reverberatory or air furnace, fired with mineral coal or coke, the flame being kindled and maintained by natural draught. A furnace of this type, used in Flintshire for the smelting of lead ore and in Bristol for copper ore, was illustrated and described in



1 exterior walls; 2 ventilator and ashpit; 3 tap hole (in the front wall, not visible); 4 iron grate; 5 fire place; 6 interior of the oven; 7 hearth with sand bottom; 8 space for molten metal; 9 slag hole; 10 flue; 11 aperture for charging the ore.

1 ***Air furnace used at Bristol for the smelting of copper ore (longitudinal section). From Schlueter[5], plate XLII***

Manuscript received 25 June 1959.
Dr Schubert is Historical Investigator to The Iron and Steel Institute.

detail in 1738 by Christoph Andreas Schlueter, a tithe-collector and surveyor in the mining district of the Lower Hartz mountains in Germany.

The dimensions of the furnace were: length 18 ft, breadth 12 ft, height 9 ft from the ground, smelting hearth 3 ft above the ground.

The new impetus given to brass manufacture at Bristol made England almost independent of overseas imports. In a pamphlet of 1712, English merchants and importers asserted that English manufacturers had brought the art of making brass wire to 'such a perfection as to undermine and almost totally exclude the importation from Holland and Germany', which previously had been a considerable item.[6]

Darby, however, was far-seeing enough to realize that pots and kettles, for which there was a wide demand, were too expensive if they were made of brass. He therefore began to consider the use of a cheaper material, such as cast iron. He set his foreign workers to try casting iron pots in sand, but several trials were unsuccessful. At this crucial moment, one of his workmen, a former shepherd from Wales, John Thomas, who had joined Darby to learn how to make malt mills, carried out a trial that proved successful.

Subsequently, Darby applied for, and obtained, a patent (no.380), which was issued on 19 April 1707.[7] The patent secured him the sole right to use his invention, which was 'a new way of casting iron bellied pots, and other iron bellied ware in sand only, without loam or clay', a method which he considered to be more perfect and cheaper than those formerly used. Although the exact nature of Darby's invention is not disclosed in the patent, the conclusion is that he should be credited with the introduction of dry-sand moulding in conjunction with the multipart moulding boxes. There dry sand was not only cheaper than loam, but it also had the advantage of not being liable to generate steam when the hot iron was poured into the mould. In this way, the mould would not be ruptured nor the casting spoiled by steam.[8] The pot that became the typical Darby product was a three-legged cauldron with the largest diameter at the middle.*

His success in casting iron pots, which would compete with their brass pots, cannot have pleased Darby's partners. This was probably the reason why he separated from them and formed the Bristol Iron Company on premises at Cheese Lane. John Thomas, who had helped him in casting, was bound to be his assistant for a period of three years from January 1707, and not to disclose the art of casting and moulding iron pots.[9]

An air furnace was adequate for the production of small castings, such as pots and kettles. But it was not spacious enough to contain a sufficient quantity of liquid iron for castings of a larger size, such as fire backs and large cauldrons called 'furnaces' corresponding to the modern boiling pans known as 'coppers', which generally contained 20–30 gal or even more. To extend the business beyond the production of articles of a smaller size, a blast-furnace was required.

Hearing of a vacant ironworks at Coalbrookdale in the manor of Madeley, Shropshire, Darby took a lease and moved there in September 1708. His brother-in-law, Thomas Harvey, who had interests in Shropshire forges, may have directed his attention to Coalbrookdale.[10] There were, however, other factors which might have been more deciding such as the position of the works near the Severn. In those days the Severn was one of the most important rivers for trade. Traffic on it linked the principal markets from Welshpool and Shrewsbury via Bewdley down to Gloucester and Bristol,[11] and this would make it possible for Darby to preserve his business connections with Bristol. An additional factor, which recently has been pointed out,[12] was that Darby already in his Bristol period learnt of the use of Shropshire coal in the metal industry and began to realize the value of its properties (very low sulphur content) for ironmaking. This, above all, may have induced him to move his activity to the source of supply, the Shropshire coalfields.

Long before Darby came, a very intensive industrial activity had developed in the neighbourhood of the coal measures in Shropshire. It was not confined to districts near the roads, but in the course of the seventeenth century several industries developed in the hills sloping up from both banks of the Severn at Broseley. These included the manufacture of bricks, tiles, and all kind of earthenware, while the manufacture of tobacco pipes was also of high repute. Before 1700, enterprising traders had begun to extract tar, pitch, and oil from shale. All those growing industries were facilitated by the opportunities of water transport on the Severn and of mining coal above the level of free drainage. The total output of the Shropshire coalfields had increased from about 6 000 tons/year before the accession of Elizabeth I in 1558 to about 150 000 tons/year at the end of the seventeenth century.[13]

In September 1708, Abraham Darby had taken over a lease of a furnace and forge at Coalbrookdale for the remaining eight years of a former lease, and of the house called White End, where he subsequently resided. The rent for the works and the house was £40 a year. In the beginning Darby managed both the works at Coalbrookdale and at Cheese Lane in Bristol; first single-handed until 8 February 1710 at which date he made an agreement of partnership with James Peters at Bristol and Griffin Prankard of Somerton who took one and two sixteenths respectively in both works. After the dissolution of the short-lived partnership (before 1711), Darby gave up his interests in the Bristol works and concentrated on Coalbrookdale only.[14]

The last quarter of 1708 was used for making the necessary preparations for a blast. Raw materials and fuel were accumulated in sufficient quantities. The furnace was reconditioned by breaking out the old hearth and replacing it by a new one and by repairing the lining of the boshes. Most important was the fixing of new bellows, since these supplied the air blast for smelting.

The bellows were made from 9 November to 22 December 1708, but apparently they were not completely satisfactory, for on 9 and 13 January considerable expense was incurred by material for, and work on, the bellows. The expense on the bellows was considerably higher than was usual on bellows for

* The method of moulding is described by Mott who also supplied a drawing of a mould in use around 1830. (*See* Lecture, page 30, and Fig. 5.)

contemporary charcoal furnaces* but the result was a more powerful blowing apparatus. A stronger airblast was absolutely essential if the new fuel, obtained from mineral coal and requiring a higher temperature, was to be substituted for the expensive charcoal then generally used for ironsmelting.

The preparation immediately preceding blowing was to pre-heat the furnace. The object was to remove any moisture which might evaporate from the walls into the interior during smelting. At Coalbrookdale this started on Christmas eve 1708. There were two campaigns in 1709: the first from 4 January to 30 June and the second from July to December. The output in the first three quarters of the year was about 75% pigs and 25% castings (including 5% of bellied pots). By the end of 1709 production of pots had increased considerably.[15] Based on very detailed calculations Dr Mott arrived at the conclusion that Darby quite clearly 'used coke alone' in 1709, and that all 'big coal was coked'.[16]

Serious objections to this have recently been raised by Flinn[17]; his argument is based upon important documentary evidence, the first of which is a letter of 1775 by Abiah Darby, the wife of his son, the second Abraham Darby.† In her letter she distinguished three consecutive phases in the application of fuel for ironsmelting by her father-in-law at Coalbrookdale. In the first of these, Darby cast iron from the furnace 'that blowed with wood charcoal, for it was not yet thought of to blow with pit coal'. 'Some time after', he tried to smelt 'with raw coal as it came out of the mines, but it did not answer'. Lastly, he 'had the coal coaked into cynder, as it is done for drying malt and then he succeeded'.

Abiah Darby's description of the process gradually developing from charcoal to coke is supported by Samuel Smiles whose remarks were based on Darby's 'Blast Furnace Memorandum Book' which he examined but which cannot now be traced. According to Smiles, the fuel appears 'to have been at first entirely charcoal, but the growing scarcity of wood seems to have been gradually led for the use of coke and peat'.[18] The evidence of Abiah Darby and Smiles makes it unlikely that the gradual process of adopting coke as the sole fuel would be completed in the first year of its application. Also, in 1709 a patent for smelting iron 'with pitt coales or sea coales charked' was still in force. It had been granted to Thomas Chetle, of Berrow Hill, parish of Feckenham, in Worcestershire on 20 December 1695 for fourteen years.* To date, however, there is no evidence that the patent of 1695 was put into practice.

An argument which supports Mott's conclusion that Darby smelted iron with coke as early as in 1709 is that the mineral coal purchased in large quantities was not disposed of to others, which is shown by the absence of any records of such dealings.[19]

The use of mineral coal by a contemporary ironmaster in the immediate vicinity of Coalbrookdale might cast some light upon the situation. On 20 October 1710 a lease was granted by Robert Slaney, the owner of a furnace in the parish of Kemberton, northeast of Coalbrookdale, to Richard Hartshorne of Ketley, parish of Wellington, and George Benbow of Malinslee, parish of Dawley, for twenty-one years.† They were granted Slaney's mines of coal and ironstone in the manor of Dawley.‡ The lessees were given permission to 'make firehearths and convert the said coales' or part of them 'into charcoale, soe as such hearths are not made above 30 yards from the pitt mount'. Secondly, they should supply Slaney at his dwelling house with 'good coales' to be spent at his house at the rate of 3*s* a load which should not exceed one stack (35 cwt). The coals shall be taken from the above mentioned pits or other 'colepits' of the lessees and be delivered at their expense. Thirdly, all coals which Slaney wants 'to use for any of his ironworks or other use', shall be supplied by the lessees at the rate of 4*s* the load which shall also contain one stack. The fourth condition was that all 'lamp' (i.e. lump) coal which shall be carried on horseback, should be delivered at 3*s* a dozen, 'and each horse not to carry above one bag of coales on the top of each horse load'. Ironstone required by Slaney should be 'used at Kemberton furnace onely', and the lessees should be notified of the quantities required at least six months before each blast. Slaney was to pay the miners' wages within one year after delivery and any taxes, and for the ironstone 6*s* a dozen of 'all flat stone' and 7*s* for 'all tall stone'.

Thus, that part of pit coal which came from the mines and was converted into coke was coked in 'hearths' not above 30 yards distant from the pit mount which suggests that coke was made on the coalfields, nowhere near a house or ironworks. There is nothing to indicate that coke was used at the ironworks. The small or lump coals apparently used were for roasting

* The statement by T. S. Ashton ('*Iron and Steel in the Industrial Revolution*', 31; 1924, Manchester University Press) is supported by the expenses for making the bellows, the total of which was £32 6*s* 10*d* in November and December 1708 (Shrewsbury Public Library, ms 328, fols 2, 4–5). Additional expenses in January 1709 amounted to £7 2*s* 9*d* (*ibid.*, fols 6–7). To this should be added a part of a summary payment made on 9 January 1709 for carriage of 'belos bordes, lime etc.' amounting to £2 10*s* 0*d* so that the total came to about £40 which is about £14 more than that for bellows in the charcoal furnaces of the period, according to Raistrick, 32.

† Ashton, *op. cit.*, 249–252. Abiah's report cannot be invalidated by referring to her 'advanced age' (R. A. Mott: *Gas World*, 1) for she was 59 years old when she wrote the letter. The reliability of her report is strengthened by sources she referred to, such as information from her husband (Darby's son), and from a person 'still living whose father came here as a workman at the first beginning of these Pit Works'.

* Birmingham, Reference Library 571053: Chetle is named in a land-tax assessment of 1705 under Berrow, i.e. Berrow Hill in the parish of Feckenham. Worcestershire Record Office 705: 33/13. The author is indebted to the county archivist Mr E. H. Sargeant for this information.

† Shrewsbury County Record Office 796/205. The author is indebted to Miss M. Hill, M.A., county archivist, for drawing his attention to this document.

‡ Richard Hartshorne held the lease of the Madeley Wood collieries and delivered large quantities of coal and ironstone to Coalbrookdale in 1709 (*Gas World*, 4–5, Raistrick, 36–37). In 1716 he leased the tithe of Ketley for seven years. Shrewsbury, County Record Office 625/-. In 1728 he was lessee of the coalworks at Oakengate and Wombridge, which belonged to the Charltons of Apley Castle in Shropshire and must have been considerable since the annual rent was £100 (*ibid.* 784). The lease of these coal and ironstone mines in the manor of Dawley was taken by Abraham Darby II in 1753 (Raistrick, 70).

the iron ore as at Coalbrookdale.* The best coal was sent either to the ironworks or to the house of the mine owner. Applying this to Coalbrookdale, it seems that Darby used a part of the coal delivered to him at his house at White End and probably also in the houses of his workers, which was an old custom in the iron industry.

There was still some activity in Coalbrookdale requiring mineral coal or coke, which disproves the assumption that all the coal obtained from the pits was converted into coke for ironmaking. Some coal or coke was absorbed in the drying and curing of malt, for Abraham Darby had started a malt house at Coalbrookdale which was carried on as a small family business within the Darby family for almost a century.[20] In the accounts from November 1708 to 3 April 1709 there are three entries referring to the purchase of malt.†

Mineral coal was also used in the manufacture of brass which was carried on at Coalbrookdale until well into the middle of the century. Coalbrookdale was very favourably placed for the brass and copper trade, since it was within easy reach of Birmingham, the great brass and copper market of the Midlands. In 1714, Darby received 20 tons of copper ore from Coniston in Furness, sent by the Backbarrow Company through their agent Samuel Milner via Pennybridge and Chepstow.[21] In the inventory of the works in 1718 there are various items referring to brass and copper trade. In addition to brass kettles, mortars, and pot patterns, 1 cwt of old brass in the smith's shop, 12 lb of new copper and 30 lb of brass in the office are mentioned. There also was a 'copper Ware House' and a 'Copper House'.[22]

A letter written on 6 October 1737 by Thomas Dorsett who had a lease of Withyford forge on the river Roden, north east of Shrewsbury, until his death in 1759, tells something of brassmaking at Coalbrookdale by the Darbys. It shows that Abraham Darby II and a relative, Thomas Harvey, intended jointly to erect a 'mill to rowle brass' upon the river Tern on land belonging to Thomas Marwood, a well known Shrewsbury draper. It was pointed out that they would 'not smelt any of the oar (ore) at that work, it being to be done at Coalbrookdale', and that the proposed work 'would be only a rowling mill to rowl brass plates and to make those up into kettles and other goods'.[23] That brass actually was made at Coalbrookdale is proved by a witness deposition of a brassfounder in 1754.‡

To arrive at a conclusion, there is a dilemma in respect of the fuel applied: either a gradual process from charcoal, to raw coal and lastly to coke, or, iron-smelting with coke exclusively from January 1709.

There is no evidence of charcoal being used in 1709 at Coalbrookdale. The large quantities of coal obtained from the mines of the largest coal-mine owners in the manors of Dawley and Madeley leave no doubt that they were mineral coal. Making allowance for some quantities used for other purposes as shown above, large quantities of coal would still be left for the production of castings and pigs. The terms used such as 'charking, coling, cole, charcoal' give no definite clue as to the nature of the fuel. They were applied to coking because of the similarity of the process to charcoal-burning. This is apparent in the document of 1710, in which the product of the coking of pitcoal is termed 'charcoal'. In these circumstances it is more likely that the items, 'charking and coling coals', occurring in the accounts of 1708–1709 refer to coke and not to charcoal, which would support Mott's thesis. In any case, the substitution of coke for any other fuel was completed before 1718,[24] since according to the inventory large quantities of 'coaks' were at the tunnel heads of both the Old and the New blast-furnaces ready for charging.[25] As Abraham Darby, who died in May 1717, was a sick man during the last eighteen months of his life and depended upon his employees for most of the conduct of his business, it is very unlikely that the process was completed after 1716.[26] Until more evidence is unearthed, it is impossible to fix a precise date for the first successful application of coke as a fuel for iron-smelting; however, there is no doubt that Abraham Darby achieved it.

To make up for the lower production of his coke blast-furnace (compared with that of a charcoal blast-furnace) he built a second furnace in 1715 at the cost of £1 500, and in the following year he acquired a half share of the Vale Royal furnace near Oulton, Cheshire.[27] His next venture was the erection of a blast-furnace near Dolgelly, in Merionethshire. Darby chose John Kelsall, who also belonged to the Society of Friends, to be the clerk (i.e. manager and accountant) of the furnace. In January 1714, Kelsall stayed for 2–3 weeks at Coalbrookdale at the house of old John Darby, Abraham's father, so that he could be, to use his words, 'instructed in their Method and Form of business'. The furnace, however, was not erected before 1718 after Abraham Darby's premature death.[28]

Abraham Darby, who died on 5 May 1717 at the age of 39, was an extremely active and enterprising man, always eager to improve his inventions and to expand his business. As his daughter-in-law described him, he was 'a religious good man'. Until the very end of his life, though stricken with illness, he conscientiously attended the meetings of the Society of Friends where he was greatly appreciated for his sermons and his prayers. By the personal contacts made on his frequent journeys, he had acquired a rare wisdom, which is shown by his successor acting as a mediator between William Rawlinson of Backbarrow furnace, in Furness, and Edward Hall, who had set up a rival furnace at Cunsey.[29] His premature death prevented him from seeing and enjoying the full fruits of his endeavours, but he lives on in history as the 'great founder' who laid the foundations of the modern coke-iron industry.

* R. A. Mott: Lecture, 20. It would also be used for the preliminary heating of the furnace which was often done with mineral coal. (Schubert, *op. cit.*, 234.)

† Ms 328, fols 2, 7, 11. One old malt mill stood in the copper warehouse and three malt mills in the old store room are referred to in the inventory of 1718 (Raistrick, 284).

‡ 'George Thomas of Coalbrookdale, parish of Madeley, brassfounder', age 37 years. Public Record Office, Exchequer Depositions by Commission, 27 Geo. II, Hil. 8.

REFERENCES

1. R. A. Mott: *Gas World* (Coking section), 1957, 5 January (subsequently referred to as R. A. Mott: *Gas World*).
R. A. Mott: 'Abraham Darby (I and II) and the coal-iron industry'; paper presented to the Newcomen Society, London, 11 December 1959. (Subsequently referred to as R. A. Mott: Lecture.)

A. RAISTRICK: 'Dynasty of iron founders,' 1953, London and New York, Longmans, Green and Co. (Subsequently referred to as A. Raistrick).
2. Central Library Dudley, Dudley papers box 5 bundle 5 (*see also* ref. 4, 17).
3. H. HAMILTON: 'The English brass and copper industries', 108 *et seq.*, 333–334; 1926, London, Longmans.
4. A. RAISTRICK: 'Quakers in science and industry', 190–192; 1950, London, Bannisdale Press.
5. C. A. SCHLUETER: 'Gruendlicher Unterricht von Huettewerken', plate XLII, explanation, 110–113; 1738, Braunschweig.
6. H. HAMILTON: *op. cit.*, 285.
7. Public Record Office, Chancery Patent Roll no.3461, membrane 7.
8. H. R. SCHUBERT: 'History of the British Iron and Steel Industry *c.* 450 BC–AD 1785', 268–269: 1957, London, Routledge and Kegan Paul.
9. A. RAISTRICK: 22.
10. R. A. MOTT: Lecture, 16.
11. A. RAISTRICK: 25.
12. J. R. HARRIS: *Edgar Allen News*, 1958, **37**, 204.
13. J. U. NEF: 'The rise of the British Coal Industry', **1**, 265; 1932, London, G. Routledge.
Victoria County History, Shropshire, **1**, 440–449, 458–461.
14. A. RAISTRICK: 214–226.
15. R. A. MOTT: *Gas World*, 4, 6.
16. R. A. MOTT: *Gas World*, 4, 7; Lecture, 20.
17. M. W. FLINN: *Economica*, 1959, 54–59.
18. S. SMILES: 'Industrial biography: Ironworkers and toolmakers', 1st edn., 82–83; 1863, London.
19. A. RAISTRICK: 36.
20. A. RAISTRICK: 228.
21. J. D. MARSHALL: 'Furness and the industrial revolution', 47: 1958, Barrow-in-Furness.
22. A. RAISTRICK: 280 *et seq.*
23. Shrewsbury, County Record Office, Attingham collection. Photograph kindly supplied by the county archivist Miss M. Hill, M.A.
24. A. RAISTRICK: 36.
R. A. MOTT: *Gas World*, 3, 4, 6.
25. A. RAISTRICK: 281, 283.
26. A. RAISTRICK: 45, 47.
27. A. RAISTRICK: 32, 43.
28. Kelsall's Diary, Friends House, London, ms 194. For details of the furnace *see* H. R. Schubert: *op. cit.*, 373–374.
29. A. RAISTRICK: 42.

Stal *in English*

Number 3 (March 1959) of the cover-to-cover translation of the Russian journal *Stal'* has been published, and subsequent issues should appear at about monthly intervals. Main contents of nos.3 and 4 are given below. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute.

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I. G. Polovchenko et al.

Multicyclones on sintering machines *A. K. Rudkov*

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I. G. Polovchenko et al.

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Accelerated pouring of steel
E. V. Verkhovtsev and S. P. Bakumenko

Automatic control of thermal conditions of OH furnaces at Kuznetsk combine *M. M. Epshtein*

Rolling and tube production

High-durability inserts for rod-mill guides
I.S. Trishevskii et al.

Separation of pack-rolled sheets *I. B. Rubinshtein*

New method of pickling high-alloy steel tubes
N. V. Bogoyavlenskaya and Ya. N. Lipkin

Metal science and heat treatment

Protecting gas envelopes formed of commercial nitrogen for heat-treatment of steel *L. V. Beloruchev and A.K. Shvachkin*

Fatigue strength of heat-treated rails containing arsenic
L. L. Pinkhusovich et al.

Economics and production

Net cost of steam in waste-heat units *P. V. Anan'ev*

Prevention of brown ferric oxide fumes by steam blowing

H. Kosmider, H. Neuhaus, and P. E. Hardt

SYNOPSIS

The brown fumes discharged during Bessemer operation with oxygen-enriched blast and in top-blowing, are probably originally composed of evaporated iron, which rapidly oxidizes to ferric oxide, since the vapour pressure of molten iron reaches atmospheric pressure at somewhat less than 3 000°C. Such a temperature may be reached locally in top- and in bottom-blowing with oxygen, so that evaporation may take place. The small size of the particles, 10–100mμ, seems to confirm the evaporation theory, though against it is the fact that brown fumes are not produced when oxygen is passed over carbon-free iron and the theory of Kohlmeyer and Spandau that iron carbonyl enters into the evaporation of iron.

It has been found, however, that with oxygen–steam and oxygen–water mixtures, which reduce the temperature of reaction since heat is required for the evaporation of water and the dissociation of steam, very little fume is produced. Thus, steam or atomized water is advocated as a means of reducing fume. In basic Bessemer practice, when oxygen-enrichment is carried out up to the end of the dephosphorizing period, steam addition will also be necessary to the end of the blow. Care should be taken to avoid condensation in the windbox, by keeping blast temperature up; for a 10% steam addition, a temperature of 80°C should be maintained. The economic effect of the heat losses from steam use in the convector is hard to estimate and may be serious, but in desiliconization and in refining in the open-hearth heat losses from this cause are of secondary importance. 1658

Formation of brown fumes as a result of the use of oxygen

IN RECENT YEARS the problem of dust and smoke suppression in industrial areas has been widely discussed, and Clean-air acts have already been passed or are in the process of being drafted in several countries. The iron and steel industry, however, has been engaged with considerable success for a period of more than thirty years in an intensive dust suppression campaign,[1] so that nowadays one cannot imagine an iron and steelworks without a gas-purifying plant, though a complete solution to the problem of brown ferric oxide fumes, a result of oxygen metallurgy, has not yet been found.

Since the introduction of gaseous oxygen into steelworks and particularly into basic Bessemer steelmaking practice, brown fumes have continually been discharged. As far as is known these fumes are not detrimental to health. They are probably formed from iron vapour, which on exposure to air, i.e. when leaving the furnaces or converters, oxidizes to ferric oxide. Very high local temperatures, producing evaporation of iron and some accompanying elements, are reached during the reaction between the more or less oxygen-rich refining gases and the iron or steel bath. A rough calculation of the local temperature peaks expected at the place of reaction was carried out[2] and the results obtained were later confirmed by experiments on bottom-blown converters.[3]

The highest reaction temperature is reached when blowing pure oxygen through a lance either above or immersed in the metal bath. Temperatures approaching 3000°C were reached where the vapour pressure of pure iron exceeded 14·22 lb/in². Figure 1 shows the reactions and vapour-pressure curves for pure iron. In bottom-blown converters working with 21–40 vol-% oxygen-enriched air, the temperature is not quite as high at the place where reaction occurs. In oxygen-enriched air blowing the fumes are not quite as dense, the density varying with the temperature of the heat. Again the size of the individual particles, $< 0{\cdot}000039$ in. ($< 0{\cdot}1\mu$), supports the view that the brown fumes are an evaporation product. The particle size of the fume lies to some extent below the wavelength of visible light thus causing certain optical effects simulating a considerably greater dust discharge than actually exists.

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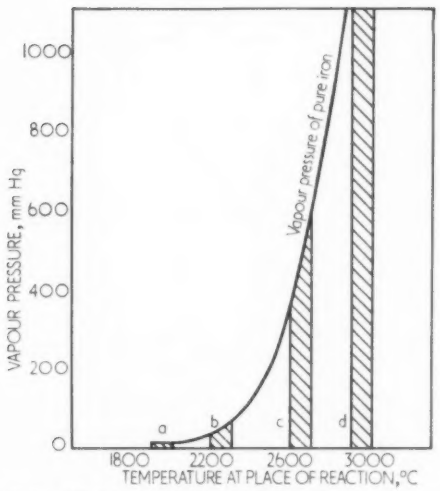
Recent BISRA laboratory tests have considerably discredited this theory, which endeavours to explain the formation of brown fumes.[4] It was discovered that hardly any brown fumes developed when oxygen was passed over carbon-free iron. Kohlmeyer and Spandau[5] found that gasification of iron is brought about by means of iron carbony, $Fe(CO)_x$. These findings did not, however, agree with those made during the dephosphorization period, i.e. with nearly carbon-free heats, where the densest fumes are being produced.

It is absolutely essential for a clear distinction to be drawn between fumes on the one hand and dust on the other. Owing to their size, coarse dust particles settle more easily. This type of dust is generally found in the immediate vicinity of the steelworks as so-called 'roof-dust', and efficient separation of this type of dust does not present any particular problems.[6]

Conversely, the suppression of the brown ferric oxide fumes is not immediately possible owing to its



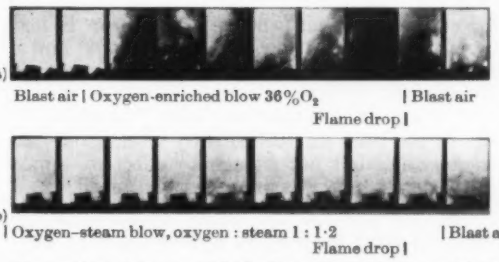
Refining with (*a*) Oxygen–steam mixture 1 : 1·2 (vol)
(*b*) Blast air
(*c*) 35% oxygen-enriched blast
(*d*) Pure oxygen

1 *Temperature at place of reaction and vapour pressure of iron*

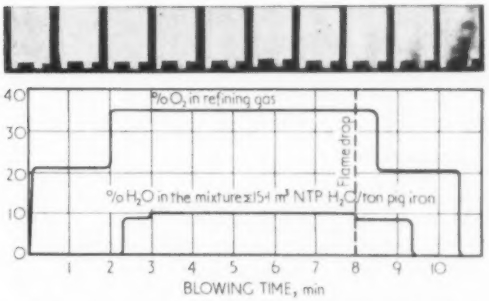
aerosol-like dispersion. In top-blowing processes, considerable expense is incurred by having to install gas purifying equipment. Additional snags appear in the case of bottom-blowing owing to the comparatively higher volume of waste gases and infiltrated air. The intrinsic difficulties of this problem and their possible solutions have been reported by Dehne.[7]

Effect of steam addition to the blast in a bottom-blown converter

Apart from the methods concerned with the suppression of brown fumes there exist others attempting to prevent their formation altogether. Converter practice has shown that brown ferric oxide fumes can be partly prevented by blowing with oxygen–steam mixtures.[8] Hardly any coloration of the exit gas is observed in an oxygen–steam blow with an oxygen concentration of 45–50 vol-%. This particular phenomenon can be explained since owing to the heat of dissociation of the steam, the temperatures reached fall too low to produce any appreciable vapour pressure of pure iron at the point where the reactions between the refining gases and the metal are taking place. This working hypothesis makes possible the reduction or even virtual elimination of evaporation of iron by cooling of the point where reaction occurs, commonly referred to as the point of combustion.



2 *Comparison between optical effects when blowing with O_2-enriched blast and with $O_2 + H_2O$-mixtures*



3 *Heat with O_2-enriched blast and high steam-enrichment*

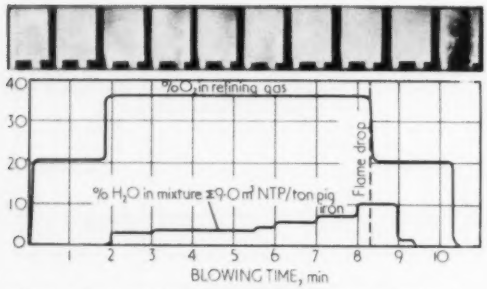
According to this theory any subsequent cooling or spraying of the ferric oxide fumes above the bath, a method which has frequently been recommended, is of doubtful value.

As a result of the promising behaviour of oxygen–steam blows, tests were carried out at the Klöckner-Haspe works to obtain reliable data on the prevention of brown fumes. The tests were, however, mainly concerned with oxygen-enriched blows in converter plants. In addition, considerable light was thrown on conditions existing during top-blowing with a lance.

The main tests were carried out in a 25-ton converter which had been fitted with the necessary measuring and control instruments for blowing with oxygen-enriched blast and oxygen–steam mixtures. In normal converter practice a 35–38%O_2 enrichment is used after 2–3-min blowing time. As a result of the excessive formation of brown fumes, no oxygen-enrichment is used in the dephosphorization period at the end of the converter process. In the tests the quantities of steam added to the normal oxygen-enriched blast mixtures were varied. Throughout the tests dust readings were taken in the waste gases at the top of the chimney and the optical effect was recorded by colour-photography. This optical image is suitable for comparison with the standard and other working procedures.

The pictures shown in Fig.2*a* indicate the colour of the waste gases in the converter chimney, where they are normally discharged during an oxygen-enriched blow. As the blowing time in a bottom-blown converter is quite different, depending on blowing area and blowing gas, it is reckoned as 100% and represented by ten photographs. Below the varying fume densities are shown the composition of the refining gas in the relevant reference period. The brown fumes appear initially after about 2 min, i.e. coinciding with the oxygen-enrichment of the blast. The density of the fumes is considerably lower than during the subsequent dephosphorization phase, because these waste gases are strongly diluted by CO_2 during this period. The density of the fume increases shortly before the flame drops, and lightens again only in the dephosphorization period when blowing with ordinary air.

For comparison, fumes discharged during an oxygen–steam blow, where refining was carried out with a mixture consisting of 47 vol-% oxygen and 53 vol-% steam, are shown in Fig.2*b*. Because of the different blowing times everything has been expressed in terms of 100%. Hardly any brown fumes and only slightly discoloured waste gases are discharged from the converter during an oxygen–steam blow.

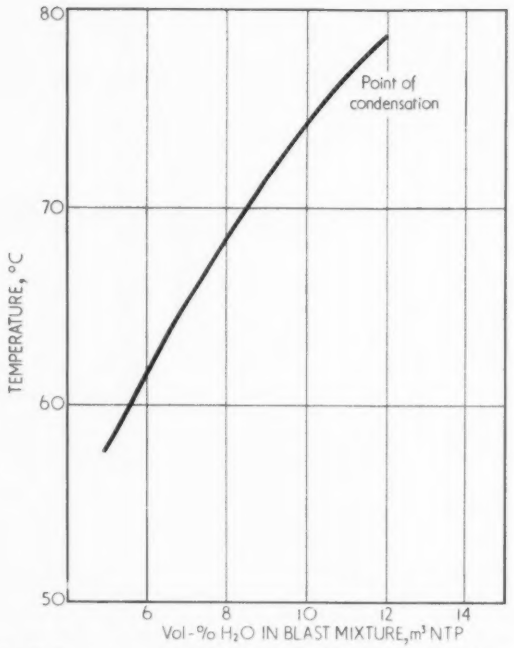


4 *Oxygen-enriched blow with graduated steam additions*

A large number of oxygen-enriched test blows were carried out, during which increasing amounts of superheated steam were added during the oxygen-enrichment period. Figure 3 shows the optical effect produced by a 10% steam addition to the blast mixture. The bottom part of this diagram gives the times at which oxygen-enrichment and steam-enrichment occurred, and also the concentration of the blast mixture. It can be seen that under these test conditions such a steam-enrichment eliminates all traces of brown fumes at the chimney top. Fumes were formed only during the last minute of the blow, during the dephosphorization period, and when steam was no longer being added. In this practice 534 ft³ (26·45 lb) of steam were consumed per ton of pig iron.

An equally satisfactory result can be obtained if steam is added to the blast from the start of oxygen-enrichment, in 2% increments so as to reach 10% at the flame drop. Figure 4 shows the results thus obtained. In this case only 350 ft³ (17·61 lb) of steam per ton of pig iron was consumed. The photographs, taken in the top portion of the chimney, reveal once again that a light-brownish fume began to form in the dephosphorization period when steam was no longer added to the mixture. If the oxygen enrichment is to be extended (a frequent practice nowadays) to the dephosphorization period, then the steam enrichment will most probably have to be continued up to the end of the blow. For metallurgical reasons use of ordinary air is to be preferred during the dephosphorization period, because some time is necessary for the solution of the lime.

Any form of condensation must be strictly prevented when steam is added to an oxygen-enriched blast mixture, otherwise the desired effect will not be produced, and unless special precautions are taken considerable damage could be caused by hydration of the dolomite bottom. It is recommended that copper tuyere bottoms should be used for this method, such as are already frequently used in basic Bessemer practice. The condensation point, below which one should not go at a blast pressure of 35·56 lb/in² to be sure of avoiding all forms of condensation has been plotted in Fig.5 against the steam addition, given as a vol-% of the blast mixture. For example, the condensation point lies at a steam addition of 10 vol-% of blast mixture at about 75°C. The blast mixture, including oxygen, should in this case have an inlet temperature of 80°C in the blast box to avoid any condensation. As the blower house is generally situated close to the steelplant it should be easily possible to ensure such a blast temperature by insulation of the blast main.



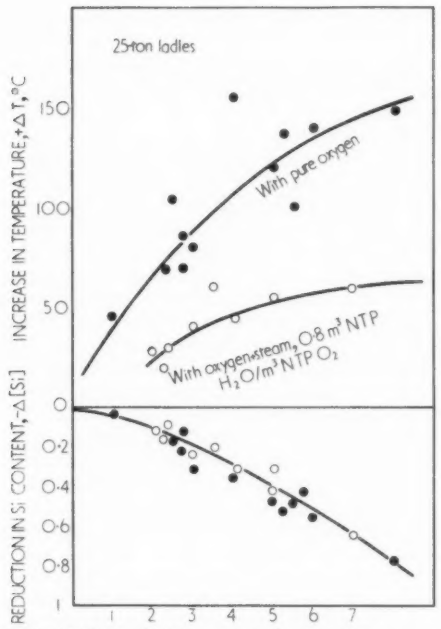
5 H_2O *contents in refining gas at 2·5 atm and point of condensation*

Excessive steam-enrichment beyond the amount required to ensure elimination of converter fumes could result in trouble through condensation, unnecessary cooling of the heat and other metallurgical defects, or in economic losses. It depends in each phase of the refining process on the most accurate incremental steam addition, as can be seen from Fig.4. It is believed that the discoloration of the waste gases could be used for controlling steam-enrichment. Alternatively, the practice already commonly used in large power stations could be adopted, where a high-speed control instrument receiving impulses from photoelectric cells located at the top of the chimney regulates the steam addition to the refining gas according to the density of the brown fumes. Such a method would permit accurate control of the steam supply with regard to the oxygen-enrichment and the reaction temperature.

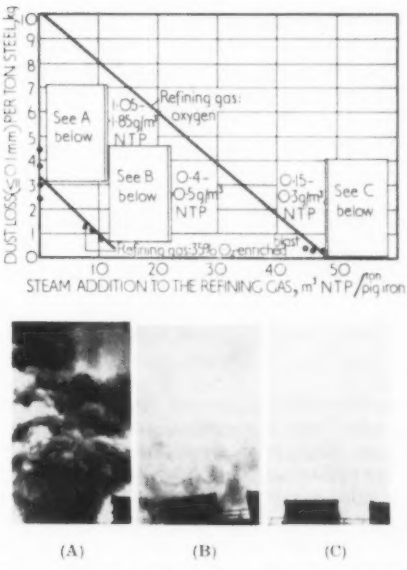
An addition of 0·0499 lb steam/ft³ corresponds to a 10% maximum steam addition to the refining gas mixture. Owing to the small quantity of steam added, this should have no new metallurgical consequences. This applies particularly to the nitrogen content of steel, and means that when a comparison is made between refining with oxygen-enriched blast and refining with oxygen-enriched blast plus minute additions of steam, no lower nitrogen content in the steel should be expected in the latter case. The addition of steam to the blast mixture slightly altered the flame characteristics, but not enough to affect its appearance.[9] Blowing time was in no way shortened.

Prevention of brown fumes during desiliconizing of pig iron

When blowing with pure oxygen the temperatures developed at the point of reaction in the pig iron or


25-ton ladles
INCREASE IN TEMPERATURE, +Δ T, °C
REDUCTION IN Si CONTENT, -Δ [Si]
With pure oxygen
With oxygen-steam, 0·8 m³ NTP H₂O/m³ NTP O₂
OXYGEN USED, m³ NTP/ton pig iron (inclusive of O₂ from steam)

6 *Preliminary refining of pig iron with and without steam addition*



7 *Dust loss and optical effect with steam addition to refining gas*

steel bath become so high that dark-brown fumes are formed through iron vaporization and oxidation. When fixed amounts of steam are mixed with the oxygen[2] the heat of dissociation of the steam reduces or even eliminates the formation of brown fumes. In an extreme case, when oxygen and steam are mixed, as in the converter process, in the ratio 1 : 1 by volume, no brown fumes form at all. With regard to the prevention of the formation of brown fumes, an adequate effect will be brought about at a ratio of steam to oxygen of 45 : 55 by volume, or at a steam addition of 0·85 ft³/ft³ oxygen. Local conditions frequently tolerate a certain discoloration of the fumes. In such a case a 3 : 1 oxygen/steam ratio by volume suffices.

Extensive condensation of the steam occurs if steam is added to the normally cold oxygen used for refining. The droplets of water thus formed are carried along by the blast and enter into the reaction with the iron melt. This suggests addition of atomized water instead of steam to the oxygen jet. The cooling effect upon the reaction zone is thereby further improved by the heat needed for water evaporation. An addition of about 0·374–0·437 lb of water/ft³ oxygen is required to prevent brown fumes when refining with pure oxygen.

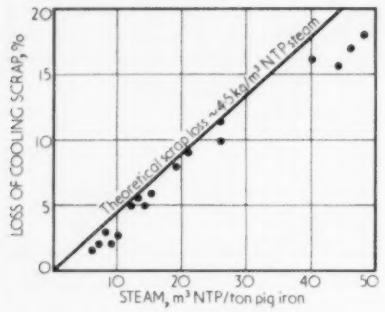
In a bottom-blown converter about ten times the quantity of steam or water has to be added to prevent vaporization of iron when blowing with pure oxygen instead of with an oxygen-enriched blast. These large quantities of steam naturally have some effect on the metallurgical behaviour of the refining process.

In the preliminary refining (desiliconizing of pig iron) the increase in temperature plays a certain part. For thermodynamic reasons the lower the temperature the more efficient is the desiliconizing process. Decarburization is retarded for the same reasons. Conversely, for reasons of economy a large increase in temperature is frequently considered beneficial during preliminary refining for desiliconizing *stahleisen* or hot metal for the OH process. Figure 6 shows the temperature behaviour of the pig iron during preliminary refining with pure oxygen and with oxygen–steam mixtures. In the lower part of the diagram the desiliconizing effect observed in basic Bessemer pig iron has been plotted against the volume of oxygen used for the blow and in the upper portion of the picture the corresponding temperature increase of the pig iron, depending on the refining medium used. Preliminary refining with oxygen–steam mixtures gives throughout a temperature rise in the pig iron of 50–70°C with a reduction in the silicon content from, e.g. 1% to 0·3%.

During the desiliconizing of pig iron, when any appreciable decarburization of the bath is undesirable, only an inadequate level is reached in the refining vessel, generally a pig-iron ladle. In this instance the gaseous hydrogen and steam (formed by the decomposition of the water contained in the gases when steam or water are added to the oxygen) can take over the task of the carbon monoxide as an agitating medium; this proved to be highly effective.

Prevention of brown fumes in the OH process

Gaseous oxygen also proved to be an effective reaction accelerator in the OH process. Thick brown fumes, which can lead in the long run to deposits on the checkers or cause damage to the roof, will form irrespective of whether the refining gas flows in through the furnace ports or is top-blown on to the bath through one or several doors. Even in this case the formation of brown fumes depends on the evaporation process and the subsequent oxidation of the evaporated iron. Similarly, thick brown fumes are formed in the converter process in virtually carbon-free heats. Identical methods of combating brown fumes can be used for OH and electric furnaces as in the preliminary refining with oxygen and steam. With



8 *Loss of cooling scrap at different steam additions*

regard to the electric furnace process it should be borne in mind that hydrogen absorption by the bath can only be offset by a simultaneous intensive boil. Apart from smoke prevention by water or steam addition, an additional agitation of the bath, which significantly improves with a lower carbon content, is beneficial from the metallurgical viewpoint. Moreover, a certain saving of gaseous oxygen is achieved, as the steam participates to some extent in the refining process. Tests[10] in the USSR where formation of brown fumes is prevented through adding water to the refining oxygen in the OH furnace, have since been published.

Dust loss and optical effect with steam addition

Figure 7 shows the losses, due to fumes, in kg/ton of steel for different blowing processes, e.g. with different steam additions. Here only dust losses of a particle size $< 0{\cdot}0039$ in. were included as these are the main components of the brown fumes and cannot be precipitated in conventional purification plants. The dust quantities when refining with 35% oxygen-enriched blast, lie between 4·85 and 10·9 lb/ton of steel. In the top-blowing process, dust quantities lying between 21·9 and 29·1 lb/ton of steel were observed.[9] The dust quantities discharged can be reduced by increasing the volume of steam added, and the lighter fumes thus produced can be allowed to escape. At a 35% oxygen enrichment with a simultaneous admixture of 584 ft³ steam/ton of pig iron only about 2·43 lb of fine dust per ton of steel could be observed. In the oxygen–steam process, during which about 1415–1760 ft³ steam was added to the pure oxygen only about 1·215 lb of fine dust per ton of steel was formed.

The dust quantities emitted have, in the scientific literature, partly been expressed in lb/ton of steel and partly in grains/ft³ of waste gas. To effect a comparison between the different dust emissions it seems better to relate them to the steel yield because the values referring to the waste gases contain varying quantities of infiltrated air and, therefore, show considerable fluctuation which makes them unreliable for purposes of comparison. The optical effect depends on the quantity of dust per unit volume of waste gas and on the fineness of the dust, three views of the top of a converter chimney have been reproduced in Fig.7 with the corresponding dust quantities for each ft³ waste gas. According to this, no visible brown fumes appeared at about 0·0656–0·131 grains fine dust/ft³ waste gas, which agrees with the results published elsewhere. In contrast it should also be mentioned that in an oxygen top-blowing process about 2·4 grains fine dust/ft³ waste gas could be detected.

Cost of prevention of brown fumes

Suppression of brown fumes through steam additions to the refining mixture requires scarcely any additional capital investment. Waste-gas purification plants, however, represent a fairly large investment item. An entirely different picture emerges with regard to operating expenses. No definite figure is available for waste-gas purification in Bessemer plants. Wet purification requires a relatively high electric power and water consumption. Electrostatic precipitators have a high power consumption which cannot always be made good by the steam credit obtained from the waste-heat boiler installed in front of them.

Addition of steam prevents vaporization of iron by reducing the temperature at the point of reaction, owing to the heat of dissociation of the steam. Thermal efficiency is, however, reduced when compared with the steamless processes. This raises the question of the economy of steam additions to the refining gas. For example, in the converter refining process a certain reduction in the quantity of the remeltable cold scrap occurs as a result of steam additions. In Fig.8 the percentage loss of cold scrap has been plotted against the steam addition in ft³/ton of pig iron. Earlier research had revealed a relation whereby for each ft³ steam added, the scrap addition would be reduced by 15 lb. This relationship, however, is not borne out by the results plotted in Fig.8. A theoretical evaluation revealed that, when working on the basis of a 75% steam dissociation, a heat loss of only 168·5 Btu/ft³ steam can be expected. This heat loss corresponds to a scrap loss of about 9·92 lb.

Figure 8 also shows the maximum possible steam addition that can be used for different refining processes. For example, if 15% scrap is added when refining basic Bessemer pig iron with an oxygen-enriched blast (32%O_2), then theoretically 1 168–1 362 ft³ steam/ton of iron can be added without incurring any risk of low finishing temperatures.

It depends on the scrap situation, i.e. the relative costs of scrap and pig iron, whether steam, added for the prevention of fumes in the converter process, represents an increase or a reduction in costs. The price of scrap will generally be lower than that of pig iron, thus reduced scrap addition represents an increase in costs. As the availability of scrap and its price can vary from one locality to the next, it is extremely difficult to arrive at any long-term forecasts. If the price of pig iron lies substantially above the scrap price, then addition of steam becomes less economical. At a rough estimate the price of ingot steel increases by about 2·30 DM/ton of ingot steel at a scrap price 25 DM, below the pig iron price and at a 6% scrap loss, due to the steam addition. A cost calculation must show what further increase in cost can be tolerated for the prevention of brown fumes (over and above the cost of major intensive purification processes). It should be remembered at this juncture that the steam addition prevents only the formation of brown fumes, i.e. fine dust.

In the converter refining process, where no additional heat is introduced externally, the prevention of

brown fumes, owing to steam addition can lead, subject to local conditions, to an uneconomical increase in the cost of the ingot steel. The situation, however, is altogether different in the case of the desiliconizing of pig iron, where the main refining occurs in the converter or OH furnace. The same is true if water or steam is used in the OH furnace when oxygen is used for speeding up the refining process. When oxygen is blown upon or into the bath in an OH furnace, a saving in fuel of the order of 16·5–35% (calculated over the entire duration of the heat) generally results. If water or steam is added in such a case to prevent formation of brown fumes, the saving in fuel is naturally less. Yet when calculated over the entire duration of the heat it remains at the most 5–8% lower than without steam additions, as results taken from Soviet sources have shown. Admixture of steam need not necessarily lead to an increase in the duration of a heat, as the rate of refining is determined merely by the volume of oxygen introduced per unit of time. Note should also be taken that a fraction of the steam actively participates in the refining reaction.

Summarizing, it can be postulated that when water or steam is added to refining gases containing higher or lower oxygen contents the formation of brown fumes can be prevented. No capital costs are incurred. The heat of dissociation of the water or steam causes a heat loss which can render the entire converter process uneconomical. These heat losses are of secondary importance in the desiliconizing of pig iron and in the use of oxygen and steam in the OH furnace to increase the refining rate.

REFERENCES

1. K. GUTHMANN: *Stahl Eisen*, 1953, **73,** 1512–1524; 1956, **76,** 45–48, 558–564.
   H. G. JONES: *Iron Coal Trades Rev.*, 1955, **170,** 839–844.
   J. M. BESKINE: *Iron Steel*, 1957, **30,** 143–146.
2. H. KOSMIDER, H. NEUHAUS, and H. KRATZENSTEIN: *Stahl Eisen*, 1954, **74,** 1045–1053. (BISITS no.497)
3. G. NAESER, W. PEPPERHOFF, and H. RIEDEL: *Stahl Eisen*, 1955, **75,** 1244–1251.
4. R. A. GRANVILLE: *Iron Coal Trades Rev.*, 1958, **176,** 566–567.
   E. T. Turkdogan and L. E. Leake: *JISI*, 1959, **192,** 162–170.
5. *Arch. Eisenhüt.*, 1944–1945, **18,** 1–6.
6. K. E. MEYER and K. H. HÜSER: Paper presented at the Bessemer Conference, 11 September 1956.
7. W. DEHNE: *Stahl Eisen*, 1957, **77,** 553–562.
8. H. KOSMIDER and P. E. HARDT: *ibid.*, 1950, **70,** 303–321.
   W.v.d. ESCHE: *ibid.*, 1950, **70,** 322–326.
9. 'Three years LD-steel', 1956, VOESt.
10. G. S. SEL'KIN and N. I. ZADALYA, *Stal*, 1957, (10), 884–887.

The dependence of M_s temperature on nickel content in nickel-alloy steels

C. A. Clark, Ph.D., A.Inst.P.

SYNOPSIS

The M_s temperature of more than 100 steels containing up to 34 wt-% of nickel have been analysed statistically. It is shown that the dependence of M_s temperature on nickel content may be represented by the equation $M_s^2 = 70{\cdot}1 \times 10^4 - 2{\cdot}90 \times 10^4 Ni + 2{\cdot}60 \times 10^2 Ni^2$. 1592

INTRODUCTION

THE MAIN OBJECTIVE of the work described in this note was to obtain a general equation for the dependence of the temperature of formation of martensite on nickel content in nickel-alloy steels. From a review of relevant literature it became clear that there was some discrepancy between M_s temperatures for low-alloy steels, as described, for example, by Steven and Haynes,[1] and values obtained from pure iron–nickel alloys by Kaufman and Cohen.[2] According to Haynes,[3] it is possible that Kaufman and Cohen actually observed the onset of bainite transformation rather than the M_s temperature for alloys containing less than about 18%Ni. It was therefore decided to include in this analysis the results on alloy steels given by Steven and Haynes[1, 3] together with those alloys investigated by Kaufman and Cohen which contained nickel in excess of 18% by weight.

These results, taken together, probably provide the best available data on the M_s temperature of nickel-bearing steels. The results on high-nickel alloys were supplemented by inclusion of data on a number of iron–carbon–nickel alloys investigated by the author using standard dilatometric techniques. The alloys listed in Table I were produced by pressing the constituent powdered elements into compacts at a pressure of 30 tons/in² and sintering *in vacuo* for 4 h at 600° C, followed by 10 h at 1200° C. The sintered compacts were then forged at 1100° C to $\frac{5}{8}$-in. dia. bar and subsequently hot rolled to $\frac{3}{8}$-in. dia. bar.

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TABLE I M_s temperatures of sintered nickel-alloy steels

Chemical composition (balance iron)		
C, wt-%	Ni, wt-%	M_s temperature, °K
0·31	26·0	193
0·12	27·0	258
0·15	27·0	245
0·22	27·5	224
0·12	28·0	246
0·19	28·0	208
0·12	29·0	229
0·17	29·0	217
0·02	30·0	271
0·11	30·0	220
0·17	30·0	188
0·13	31·0	205
0·17	31·0	107

Alloys listed in Table II were produced by a conventional air-melting technique, the processing schedule being the same as that used for the sintered alloys. The sintered alloys were free of incidental impurities, but the air-melted alloys contained about 0·2%Si and 0·5%Mn. The grain size of the sintered and air melted alloys was 5 and 7 (ASTM) respectively. Assuming its dependence on silicon content to be relatively small, the M_s temperature for the alloys in Tables I and II may be calculated approximately from the equation

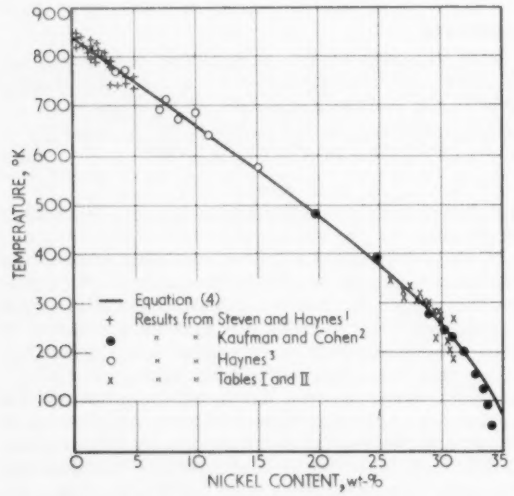
$$M_s(°K) = 1·052 - 494C - 50Mn - 26·4Ni \quad \ldots\ldots(1)$$

in which the compositions are expressed as weight percentages. The dependence of M_s on composition for low-alloy steels is given by the equation[1]

$$M_s(°K) = 834 - 474C - 33Mn - 17Ni \quad \ldots\ldots(2)$$

The constant term and the carbon and nickel coefficients in equation (1) were deduced by direct analysis of the small group of alloys given in Tables I and II. The manganese term in equation (1) was obtained by assuming that in progressing from low- to high-alloy steels the manganese coefficient increases in about the same ratio as the nickel coefficient.

These results were analysed statistically by the method of least squares, correction for alloy content other than nickel first being made according to equation (1) for alloys given in Tables I and II, and equation (2) for alloys given in references 1 and 3.



1 *Calculated and experimental M_s temperatures*

TABLE II M_s temperatures of nickel-alloy steels made by air melting

Chemical composition (balance iron)			
C, wt-%	Mn, wt-%	Ni, wt-%	M_s temperature, °K
0·20	0·43	28·3	199
0·16	0·58	28·7	194
0·13	0·53	28·9	192
0·14	0·49	29·4	191
0·17	0·56	29·7	117
0·10	0·48	29·9	204
0·15	0·41	29·9	188
0·13	0·53	30·0	173
0·18	0·52	30·6	109
0·16	0·57	30·7	104

Various possible equations were tried, but the best fit to the results on more than 100 alloys was given by the following hyperbola, in which the figures in curved brackets are the standard deviations of the parameters

$$M_s^2 = 70·1\ (0·3) \times 10^4 - 2·90\ (0·08) \times 10^4 Ni + 2·60\ (0·25) \times 10^2 Ni^2 \quad \ldots\ldots(3)$$

For convenience, this may be re-written in the form

$$\frac{(Ni - 55·8)^2}{414} - \frac{M_s^2}{107\,700} = 1 \quad \ldots\ldots(4)$$

Some of the experimental results are shown in Fig. 1, to illustrate that for alloys containing not more than 34%Ni, equation (4) gives good agreement with experiment.

By differentiation, it is readily shown that at low nickel contents equation (4) reduces to

$$M_s(°K) = 837 - 17·3Ni \quad \ldots\ldots(5)$$

which is in good agreement with the linear equation derived statistically for low-alloy steels by Steven and Haynes.[1] Similarly, for nickel contents of about 29% the dependence of M_s on nickel content may be represented approximately by the following linear equation

$$M_s(°K) = 1000 - 24·8Ni \quad \ldots\ldots(6)$$

This equation gives similar values to equation (1) within the range of nickel contents of the alloys in Tables I and II.

Finally, it should be noted that the discrepancy between equation (4) and experiment for the alloys of high nickel content arises because of the small number of results available on alloys containing nickel in excess of 32%. A slight modification of the parameters to give the equation

$$M_s^2 = 70·1 \times 10^4 - 2·74 \times 10^4 Ni + 2·60 \times 10^2 Ni^2 \quad \ldots\ldots(7)$$

gives better agreement with the results for alloys of high nickel content, although equation (3) gives better statistical agreement when all the results are considered.

ACKNOWLEDGMENTS

The author wishes to thank the Mond Nickel Company Ltd for permission to publish this paper.

REFERENCES

1. W. Steven and A. G. Haynes: *JISI*, 1956, **183**, 349–359.
2. L. Kaufman and M. Cohen: *Trans. AIME*, 1956, **206**, 1393–1401.
3. A. G. Haynes (in discussion of ref. 2): *ibid.*, 1957, **209**, 1314–1315.

The activity of ferrous oxide in silicate melts

C. Bodsworth, M.Met., Ph.D., A.I.M.

SYNOPSIS

Equilibrium measurements between hydrogen–steam mixtures and molten slags contained in solid iron crucibles have been used to determine the activity of ferrous oxide in $FeO–SiO_2$ *and* $FeO–CaO–SiO_2$ *melts at temperatures between 1 265°C and 1 365°C. The activity of ferrous oxide appears to be independent of temperature in the presence of silica alone, but is markedly temperature-dependent in the presence of lime and silica. At constant lime content the activity coefficient is raised with increasing temperature in melts of high silica content, but is lowered at low silica concentrations. The iso-activity lines at 1 600°C have been determined approximately by linear extrapolation of the experimental data.*

An equation is derived for the evaluation of the activity of ferrous oxide which gives close agreement with the experimental values over the range of composition and examined temperature. 1585

THE ACTIVITY OF FERROUS OXIDE in ferrous silicate melts over the temperature range 1 258–1 402° C has been investigated by Schuhmann and Ensio.[1] Their results indicate a positive deviation from ideality at low silica concentrations, changing to a marked negative departure as silica saturation is approached. Variation of the temperature within the range studied had no significant effect on the activity.

Elliott[2] has recently re-plotted the iso-activity contours at 1 600° C for ferrous oxide in the system $FeO–(CaO + MgO)–SiO_2$, using the experimental data of Chipman and co-workers.[3, 4, 5] Points on the $FeO–SiO_2$ binary side were obtained from the results of Schuhmann and Ensio and these were equated to 1 600° C by assuming a linear activity–temperature relationship. A very marked positive deviation from ideality is indicated, which is a maximum along the $FeO–2CaO . SiO_2$ join.

Turkdogan and Pearson[6] have determined the activity surface for ferrous oxide in melts comprising $FeO–(SiO_2 + P_2O_5)–(CaO + MgO + MnO)$, data being collated from a number of sources. No temperature dependence of the activity could be detected within the range covered, 1 550–1 650° C, in agreement with the observations of Taylor and Chipman.[3] The position of their iso-activity curves was a little different from those given by Elliott, particularly in the location of the apices. This was possibly due to the presence of P_2O_5 and MnO in some of the slags, although Turkdogan and Pearson stated that variation of the ratios of the oxides within the brackets had no significant effect upon the activity of FeO within the range of composition for which data was available.

Richardson[7] has calculated the free energy of formation (ΔG^m) surface for the ternary system FeO–CaO–SiO, using the established data for the activities in the relevant binary systems and assuming ideal mixing of the binary silicates. The partial molar free energy and hence the activity of ferrous oxide was estimated from this surface. The derived curves indicate a greater difference between the activity and the mole fraction of FeO in the orthosilicate liquids than that obtained directly from the experimental data discussed earlier.

From the published data it is not possible to isolate the effects on the FeO activity of the various cations or anions which may be present in a steelmaking slag in equilibrium with liquid iron. In all the experimental work referred to above, CaO, FeO, and SiO_2 were the principal variables. The other components varied only over rather restricted ranges, and it is probable that a small change of one minor component was masked by the simultaneous variation of the other components.

Since lime, silica, and iron oxides are the major constituents of iron and steelmaking slags, a systematic approach to the study of oxygen potentials would be to investigate initially the ternary melts. Thereafter, the modification of these slags by varying concentrations of other components should be examined. This paper details the first part of a research programme based on this approach.

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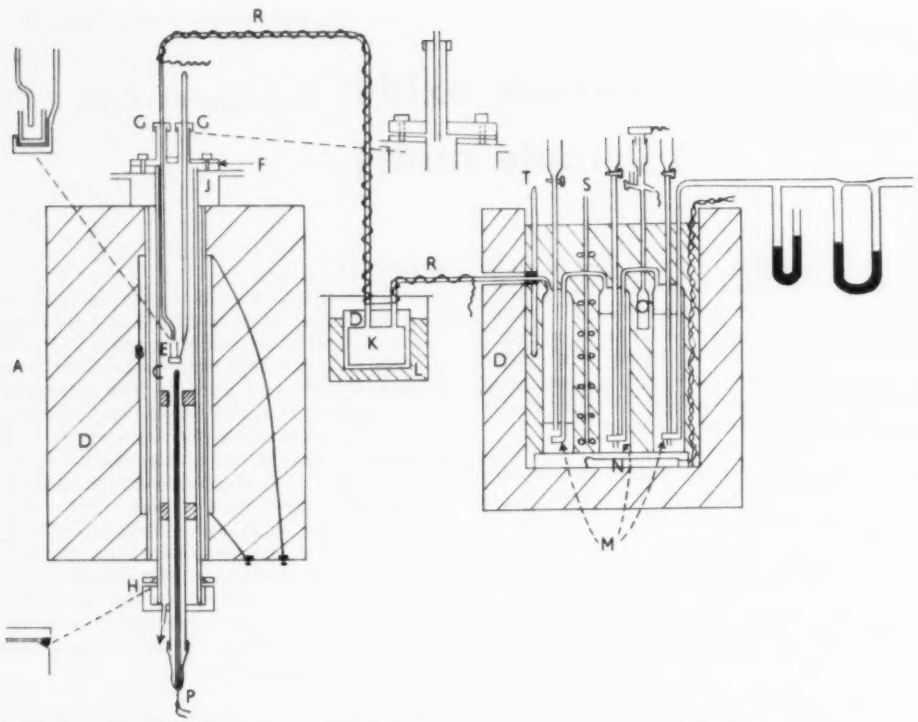
EXPERIMENTAL METHODS

Apparatus

For direct comparison with steelmaking conditions the experiments should be designed so that slags of different composition are brought to equilibrium with pure iron in the temperature range 1 550–1 700° C. However, experimentally this presents many difficulties. No known material is inert in the presence of molten iron and slags containing iron oxides. Hence, if the reaction is carried out in a crucible, contamination of the metal and the slag is inevitable. There have been a number of ingenious attempts to surmount this difficulty, notably by Taylor and Chipman,[3] but the results have not been entirely satisfactory.[8]

If the experiments are carried out in a temperature range in which a solid iron crucible can be used the problem does not arise. The activity of the ferrous oxide can then be calculated from the oxygen potential of a gas phase in equilibrium with it. This method was used by Schuhmann and Ensio[1] and it was decided to use a similar technique in the present work. However, hydrogen–steam instead of $CO–CO_2$ mixtures were used because a number of side reactions involving carbon deposition and carburization of the crucible are eliminated.



A Platinum-wound furnace
B Furnace element
C Inner tube
D Insulation
E Crucible
F Rubber gasket
G Wilson seal
H Rubber ring assembly
J Water cooler
K Katherometer
L Thermostat oil tank
M Saturator tower
N Heater
O Toluene bulb
P Thermocouple
R Heated copper tubing
S Stirrer
T Thermometer

1 *Arrangement of apparatus*

The saturator unit (Fig. 1) consisted of a water bath of 5-gal capacity, contained in a sandbox and heated by a 250-W immersion heater. The temperature was held to within $\pm 0{\cdot}02^\circ$ C of any specified value by means of a toluene thermostat. Stirrers were provided and no temperature gradient could be detected. The connection from the saturator to the crucible assembly was made with copper tubing resistance heated to 70° C. Copper was used in preference to glass to obtain the necessary flexibility in raising and lowering the gas probe at the furnace connection. To avoid the possibility of condensation occurring as the gas mixture left the saturator the exit lead was brought out through the side of the tank at a point about 4 in. below the surface of the water in the bath.

Extensive absorption tests were performed to ascertain the optimum water levels in the towers to ensure that the gas was saturated at all temperatures from 20–62° C and at flow rates of 8–15 l./h. This range of conditions proved adequate for all the subsequent experimental runs.

Since thermal diffusion errors were probable, argon was introduced into the gas mixture so that the saturated gas contained not less than 60% argon. Cylinder supplies of purified hydrogen–argon mixtures were obtained and the hydrogen content was determined accurately to two place of decimals.

A vertical, platinum-alloy-wound furnace was used to heat the reaction chamber. The temperature was controlled by a proportional controller operating from a thermocouple located in the hottest zone between the inner tube and the furnace winding. By suitable adjustment of variable resistances in series and in parallel with the winding the controller could be set to pass about 5% of the total current. By this means the furnace temperature could be held constant to within $\pm 2{\cdot}0^\circ$ C for at least 10-h periods. Baffles were inserted in the lower part of the inner tube and adjusted until, with the crucible located in position, a uniform temperature zone was attained in which the temperature varied by less than 10° C over a height of 3 in. The temperatures recorded by a thermocouple located in contact with the base of the crucible are considered to represent the mean slag temperatures and to be correct within $\pm 5^\circ$ C.

The crucible assembly used in the early experiments was similar to that described by Schuhmann and Ensio.[1] About 100 g of slag was heated to the required temperature in the sealed crucible under an atmosphere of dry, oxygen-free nitrogen. When the charge was completely molten and the temperature stabilized the H_2–H_2O–A gas mixture was introduced and the probe was lowered to just below the surface of the melt. The change in composition of the gas mixture after bubbling through the melt

was obtained by means of a rapid-acting katharometer of high sensitivity. The saturator temperature was then adjusted until no change in gas composition could be detected when the gas was passing over, or bubbling through the melt. Under these conditions any change in composition between the in-going and out-going gas mixture could be attributed to any reaction between the gas phase and the crucible assembly. When this stage was reached the saturator temperature was held constant and the gas was bubbled through the melt for a further period of at least 1 h.

Slag samples were drawn off for analysis by immersing the ends of mild-steel rods momentarily in the melt, withdrawing them rapidly into the water-cooled head of the apparatus, and holding in that position until the slag had cooled to room temperature.

Equilibrium could only be approached from the excess steam side. In several cases, however, the attainment of equilibrium was verified after taking a sample by passing the gas through the melt for a further period of 1 h, after which a second sample was removed. In each case the compositions of the two samples were identical within the limits of analytical error.

More than 30 melts were started in this apparatus and those which were finally brought to equilibrium are designated as series *AA* in Table II. Many of the runs had to be discontinued owing to fusion of the gas probe to the outlet pipe of the assembly, and no adequate means was found of counteracting this trouble.

It was observed on some of the later melts with this apparatus that the approach to equilibrium was quite rapid when the gas composition was held constant and oxidizing with respect to the slag. Examination of the used crucibles then revealed a marked region of attack of the crucible wall below the slag level. It was therefore decided to modify the procedure and to bubble a gas of constant composition through a melt of lower initial oxygen potential than the gas phase for a prescribed period of time sufficient to ensure that equilibrium had been attained. The assembly used is shown in Fig. 1.

Crucibles 1⅝ in. high, ⅝ in. internal dia. with ¼ in. wall thickness were made from best Swedish iron, and were mounted in a small quantity of alumina powder on a pedestal attached to a rod which could be adjusted vertically through a Wilson seal.

The charge, between 5 and 6 g, was accurately weighed from calculated weights of master mixtures and transferred to the crucible when in the raised position. The cover plate was clamped on to the water cooler and a blast of oxygen-free nitrogen introduced through the gas probe to flush the air from the reaction tube. After a few minutes the nitrogen supply was reduced to a steady flow and the crucible was lowered into the uniform-temperature zone of the furnace. When the charge was completely molten the hydrogen–steam–argon gas mixture was introduced with the gas probe just below the surface of the melt.

The time required to attain equilibrium was ascertained by performing a series of runs for varying periods of time, maintaining the temperature and the initial slag and gas compositions constant for each series. Typical results are given in Table I, which shows that the rate of approach to equilibrium was very rapid. The analyses of the samples treated for more than 2 h were constant within the limits of experimental error, and even after 1 h the total iron content had reached approximately the same level, although the higher ferric oxide content indicates that equilibrium had not been attained. (The analyses quoted in Table I are the mean of four to six assays for each component and the error is therefore less than the tolerance limits quoted later.) In the subsequent experiments the gas mixture was bubbled through the melt for a minimum period of 4 h, the slag composition being so adjusted that the initial iron oxide content was between 2% and 6% lower than that estimated for the equilibrium condition. Checks for the attainment of equilibrium were made at each activity level for the three and four component slags by holding occasional melts for up to 8 h before withdrawal. The accuracy of the method was also tested by treating mixtures each containing 0·5–1·0% iron oxide in excess of an equilibrium condition previously attained. These melts analysed lower in ferric oxide content, owing to the presence of oxygen-saturated iron entrapped in the slag.

TABLE I Analyses of melts, mean of 4–6 assays of each component

Melt No.	Temperature, °C	Duration of run, h	Initial composition, wt-%		Final composition, wt-%		
			Fe_TO	SiO_2	FeO	Fe_2O_3	SiO_2
*BA*1	1 305	1	68·8	31·2	71·2	2·0	26·8
*BA*2	1 302	2	68·8	31·2	71·7	1·2	27·1
*BA*3	1 298	3	68·8	31·2	71·4	1·4	27·2
*BA*4	1 303	6	68·8	31·2	71·5	1·3	27·2
*BA*5	1 305	2	63·3	36·7	71·7	1·3	27·0
*BA*6	1 304	6	63·3	36·7	71·6	1·2	27·2

After the attainment of equilibrium the gas mixture was replaced by a rapid flow of oxygen-free nitrogen and the crucible was raised as rapidly as possible into the head of the furnace. The rate of withdrawal was limited by the risk of failure of the refractory tube due to thermal shock. A routine was therefore adopted involving withdrawing the crucible by about 6 in. so that the melt was cooled to about 700° C in 3 min and then gradually continuing the withdrawal over a further period of 10 min. The solidification of the melt was complete within 1 min of the start of withdrawal and it is improbable that any significant change in composition occurred during cooling.

After removal from the furnace, the crucible was compressed to break away the slag, care being taken to prevent contamination from any alumina or scale on the outside of the crucible and to remove any splashes of slag on the inner surface. The sample was analysed as soon as possible for ferrous and ferric oxides, these estimations being generally completed within 1 h after removing the melt from the furnace.

Preparation of melts

Ferrous oxide was prepared by the decomposition of ferrous oxalate in a partial vacuum[9] and was fused with — 60 mesh Dutch sand (99·8%SiO_2) in Armco iron crucibles under an oxygen-free atmosphere to produce stock quantities of ferrous silicates of

TABLE II Analyses of FeO–SiO_2 melts

Melt No.	Temperature, °C	p_{H_2O}/p_{H_2}	$\alpha_{Fe^{+}O}$	Wt-% FeO	Wt-% Fe_2O_3	Wt-% SiO_2	Mol-% Fe_TO	Mol-% SiO_2
AA1	1 304	0·783	0·796	77·8	3·8	18·4	78·3	21·7
AA2	1 350	0·748	0·800	78·3	3·5	18·2	78·5	21·5
AA3	1 257	0·678	0·652	72·6	2·1	25·3	70·9	29·1
AA4	1 304	0·620	0·630	72·2	1·6	26·2	70·0	30·0
AA5	1 350	0·609	0·652	72·8	1·7	25·5	70·7	29·3
AA6	1 300	0·588	0·594	70·2	1·6	28·2	67·8	32·2
AA7	1 307	0·587	0·598	70·4	1·2	28·4	67·7	32·3
AA8	1 362	0·567	0·614	71·6	1·0	27·4	68·8	31·2
AA9	1 269	0·558	0·544	68·0	1·3	30·7	65·1	34·9
AA10	1 306	0·490	0·499	67·2	0·6	32·2	63·8	36·2
BA5	1 305	0·599	0·607	71·4	1·4	27·2	69·1	30·9
BA8	1 304	0·787	0·800	77·7	3·6	18·7	78·0	22·0
BA9	1 259	0·726	0·700	73·4	3·0	23·6	72·7	27·3
BA10	1 264	0·726	0·701	73·6	3·0	23·4	73·2	26·8
BA11	1 307	0·686	0·698	74·0	2·5	23·5	71·8	28·2
BA12	1 306	0·681	0·694	73·7	2·5	23·8	72·7	27·3
BA13	1 368	0·559	0·610	72·2	1·1	26·7	69·6	30·4
BA14	1 312	0·492	0·509	67·3	1·0	31·7	64·2	35·8
BA15	1 361	0·462	0·500	67·4	0·6	32·0	64·0	36·0
BA16	1 360	0·437	0·473	65·8	0·7	33·5	62·4	37·6
BA17	1 308	0·424	0·433	63·8	0·4	35·8	60·0	40·0

varying iron oxide/silica ratios. At a later stage in the work ferrous silicates containing not more than 8%Fe_2O_3 were prepared by melting together pure ferric oxide and Dutch sand in a similar manner. After the first fusion each mixture was cooled, crushed to — 40 mesh, and re-fused to ensure homogeneity.

Lime was added by means of stock mixtures which were prepared by repeated sintering of freshly calcined calcium oxide and Dutch sand in a platinum dish at 1 400° C.

Each master mixture was crushed to — 20 mesh, analysed and stored in a stoppered bottle. The experimental melts were prepared by weighing accurately the appropriate fractions of these materials and mixing thoroughly before charging the crucible. At the end of the experiment the nominal lime and silica concentrations were re-calculated, allowance being made for the increase in iron oxide content (determined by analysis). This served as a check on the accuracy of the assays.

Methods of analysis

Ferrous oxide was estimated by solution in dilute HCl containing a little HF and titration with potassium dichromate. The stannous chloride–mercuric chloride reduction method was used for total iron determination. All assays were performed in duplicate or triplicate and the mean figures recorded for ferrous oxide are considered to be correct within $\pm 0{\cdot}2\%$. The ferric oxide estimations were subject to greater error, because they represent the difference between two titrations, and are considered to be accurate to within $\pm 0{\cdot}4\%$.

Silica was determined by double dehydration and baking, followed by hydrogen fluoride treatment of the residue. Some of the silica-rich melts proved to be only partially soluble in aqueous solution and these were opened-out by fusion. These analyses are considered to be correct to $\pm 0{\cdot}25\%$.

Lime contents were estimated by separation of the oxalate and titration with potassium permanganate, and are considered to be accurate to within $\pm 0{\cdot}04\%$. Some of these assays were checked by the analytical laboratories of Messrs John Summers and Sons Ltd, Shotton.

Any total analysis which fell outside the range 99·0% to 101·0% was rejected.

RESULTS

The ferrous oxide–silica system

Schuhmann and Ensio[1] reported no temperature dependence of the activity of FeO (α_{FeO}) in this system within the temperature range of their investigations. This result was unexpected in view of the deviation from ideality. It was decided therefore to conduct a number of experiments on this system to ascertain whether the use of hydrogen–steam mixtures was more sensitive to small changes in activity levels than methods dependent on chemical analysis of the gas mixtures.

The initial series of melts was brought to equilibrium in the first type of crucible described and the analyses, corrected to total 100% are listed in Table II, together with the hydrogen/steam ratios and the calculated values of α_{FeO}. The system is not a true binary, but the concentrations of ferric oxide found were small and the error incurred by considering the total iron content of the slag as ferrous oxide is negligible. This procedure was adopted in the calculation of mole fractions, where the total iron oxides are tabulated as Fe_TO.

The reaction concerned in the establishment of equilibrium between the gas phase, the slag and the metal crucible may be expressed as:

$$H_2O_{(gas)} + Fe\gamma = H_{2(gas)} + FeO_{(slag)} \quad \ldots\ldots\ldots(1)$$

The equilibrium constant for this reaction may be written:

$$K = \frac{\alpha_{FeO} \cdot p_{H_2}}{p_{H_2O}} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

where p_{H_2} and p_{H_2O} are the partial pressure of hydrogen and steam respectively. The value of the constant was calculated from the available thermodynamic data. The standard state chosen was pure liquid ferrous oxide in equilibrium with pure iron in the γ form.

Darken and Gurry[10] have determined the partial pressures of CO and CO_2 in equilibrium with pure iron and wüstite over the temperature range 1 400–1 600° C. From their data, applying the correction for the change from δ to γ iron,

$$FeO_{(slag)} + CO_{(gas)} = Fe\gamma + CO_{(gas)} \ldots\ldots\ldots(3)$$
$$\Delta G^\circ = -12\,080 + 9{\cdot}868\,T \text{ cal/mol}$$

where ΔG° is the free-energy change and T the absolute temperature. The standard free-energy for the water gas reaction is[11]:

$$CO_{2(gas)} + H_{2(gas)} = CO_{(gas)} + H_2O_{(gas)}$$
$$\Delta G^\circ = +6\,383 - 6{\cdot}222\,T \text{ cal/mol} \quad \ldots\ldots(4)$$

adding

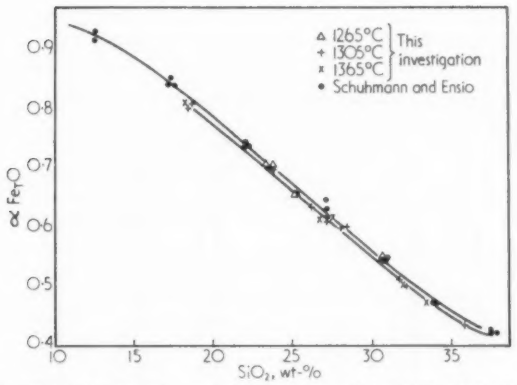
$$FeO_{(slag)} + H_{2(gas)} = Fe\gamma + H_2O_{(gas)}$$
$$\Delta G^\circ = -5\,697 + 3{\cdot}646\,T \text{ cal/mol} \quad \ldots\ldots(5)$$

hence $$\Delta G^\circ = -RT\ln\frac{\alpha_{Fe} \cdot p_{H_2O}}{\alpha_{FeO} \cdot p_{H_2}}$$

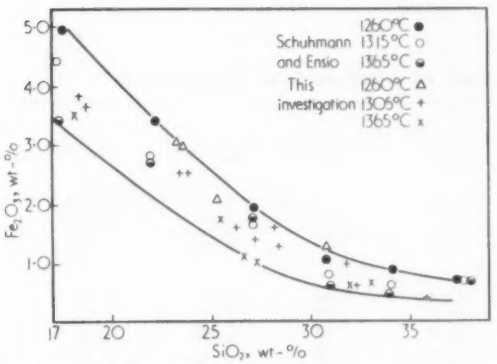
Re-arranging and substituting for ΔG° etc.:

$$\log \alpha_{FeO} = \log\frac{(p_{H_2O})}{(p_{H_2})} - \frac{1\,246}{T} + 0{\cdot}7969 \ldots\ldots(6)$$

For each run the partial pressure of steam was determined from the temperature of the saturator tank and the steam tables. The partial pressure of hydrogen in the mixture was evaluated next from the



2 *The influence of composition on the activity of* FeO *in the binary slags*



3 *Variation of* Fe_2O_3 *content with silica concentration in the binary melts*

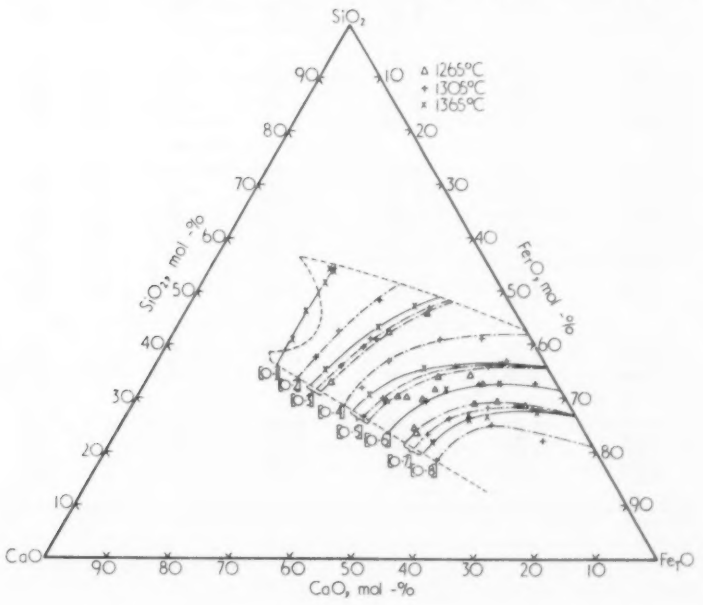
H_2/A ratio of the cylinder gas. These values were substituted in equation (6) and the activity was calculated at the temperature of the melt. If the recorded saturation temperature was in error by 0·05° C at 60° C the error in the estimated value of α_{FeO} is 0·0022. The error in α_{FeO} corresponding to a 0·05° C error decreases with temperature and is only 0·0011 at 36° C. A change of 5·0° C in the crucible temperature at 1 300° C is equivalent to a variation of 0·0048 in the activity at $\alpha_{Fe_TO} = 0{\cdot}8$ and of 0·0013 at $\alpha_{FeO} = 0{\cdot}2$.

The calculated values of α_{FeO} are plotted against wt-%SiO_2 in Fig. 2 and are compared with the values obtained by Schuhmann and Ensio.[1] The present results are best fitted by a curve drawn parallel to the mean line through their data and located at a slightly higher iron oxide content for any given value of α_{FeO}. The deviation between the two curves is equivalent to a difference of 0·009 in α_{FeO} or of 0·48% in the estimated value of SiO_2, and is well within the experimental error.

In addition to the experiments described above, a number of runs were made on melts in this system with the second form of apparatus. During the subsequent experiments on the multi-component slags, occasional binary melts were inserted to confirm that the gas mixture was saturated and that the apparatus was functioning correctly. The results obtained were consistent with those from the original apparatus and these melts are designated *BA* in the Table II. The mean line in Fig. 2 is based on all the results obtained for the binary slags.

Examination of the results obtained at the three temperatures studied reveals no significant trend and confirms the observation of Schuhmann and Ensio[1] that the activity of ferrous oxide is independent of temperature within the range studied.

The variation of ferric oxide content of the binary slags is compared with the results of the above workers in Fig. 3. Smooth curves have been drawn through their data, the upper curve representing the mean ferric oxide contents found at 1 265° C and the lower curve for 1 365° C. The present results, with



4 *Ferrous oxide iso-activity lines at 1 265°C, 1 305°C, and 1 365°C*

TABLE II Analyses of FeO–SiO_2 melts

Melt No.	Temperature, °C	p_{H_2O}/p_{H_2}	α_{Fe^+O}	Wt-% FeO	Fe_2O_3	SiO_2	Mol-% Fe_TO	SiO_2
AA1	1 304	0·783	0·796	77·8	3·8	18·4	78·3	21·7
AA2	1 350	0·748	0·800	78·3	3·5	18·2	78·5	21·5
AA3	1 257	0·678	0·652	72·6	2·1	25·3	70·9	29·1
AA4	1 304	0·626	0·630	72·2	1·6	26·2	70·0	30·0
AA5	1 350	0·609	0·652	72·8	1·7	25·5	70·7	29·3
AA6	1 300	0·588	0·594	70·2	1·6	28·2	67·8	32·2
AA7	1 307	0·587	0·598	70·4	1·2	28·4	67·7	32·3
AA8	1 362	0·567	0·614	71·6	1·0	27·4	68·8	31·2
AA9	1 269	0·558	0·544	68·0	1·3	30·7	65·1	34·9
AA10	1 306	0·490	0·499	67·2	0·6	32·2	63·8	36·2
BA5	1 305	0·599	0·607	71·4	1·4	27·2	69·1	30·9
BA8	1 304	0·787	0·800	77·7	3·6	18·7	78·0	22·0
BA9	1 259	0·726	0·700	73·4	3·0	23·6	72·7	27·3
BA10	1 264	0·726	0·701	73·6	3·0	23·4	73·2	26·8
BA11	1 307	0·686	0·698	74·0	2·5	23·5	71·8	28·2
BA12	1 306	0·681	0·694	73·7	2·5	23·8	72·7	27·3
BA13	1 368	0·559	0·610	72·2	1·1	26·7	69·6	30·4
BA14	1 312	0·492	0·509	67·3	1·0	31·7	64·2	35·8
BA15	1 361	0·462	0·500	67·4	0·6	32·0	64·0	36·0
BA16	1 360	0·437	0·473	65·8	0·7	33·5	62·4	37·6
BA17	1 308	0·424	0·433	63·8	0·4	35·8	60·0	40·0

varying iron oxide/silica ratios. At a later stage in the work ferrous silicates containing not more than 8%Fe_3O_3 were prepared by melting together pure ferric oxide and Dutch sand in a similar manner. After the first fusion each mixture was cooled, crushed to − 40 mesh, and re-fused to ensure homogeneity.

Lime was added by means of stock mixtures which were prepared by repeated sintering of freshly calcined calcium oxide and Dutch sand in a platinum dish at 1 400° C.

Each master mixture was crushed to − 20 mesh, analysed and stored in a stoppered bottle. The experimental melts were prepared by weighing accurately the appropriate fractions of these materials and mixing thoroughly before charging the crucible. At the end of the experiment the nominal lime and silica concentrations were re-calculated, allowance being made for the increase in iron oxide content (determined by analysis). This served as a check on the accuracy of the assays.

Methods of analysis

Ferrous oxide was estimated by solution in dilute HCl containing a little HF and titration with potassium dichromate. The stannous chloride–mercuric chloride reduction method was used for total iron determination. All assays were performed in duplicate or triplicate and the mean figures recorded for ferrous oxide are considered to be correct within ± 0·2%. The ferric oxide estimations were subject to greater error, because they represent the difference between two titrations, and are considered to be accurate to within ± 0·4%.

Silica was determined by double dehydration and baking, followed by hydrogen fluoride treatment of the residue. Some of the silica-rich melts proved to be only partially soluble in aqueous solution and these were opened-out by fusion. These analyses are considered to be correct to ± 0·25%.

Lime contents were estimated by separation of the oxalate and titration with potassium permanganate, and are considered to be accurate to within ± 0·04%. Some of these assays were checked by the analytical laboratories of Messrs John Summers and Sons Ltd, Shotton.

Any total analysis which fell outside the range 99·0% to 101·0% was rejected.

RESULTS

The ferrous oxide–silica system

Schuhmann and Ensio[1] reported no temperature dependence of the activity of FeO (α_{FeO}) in this system within the temperature range of their investigations. This result was unexpected in view of the deviation from ideality. It was decided therefore to conduct a number of experiments on this system to ascertain whether the use of hydrogen–steam mixtures was more sensitive to small changes in activity levels than methods dependent on chemical analysis of the gas mixtures.

The initial series of melts was brought to equilibrium in the first type of crucible described and the analyses, corrected to total 100% are listed in Table II, together with the hydrogen/steam ratios and the calculated values of α_{FeO}. The system is not a true binary, but the concentrations of ferric oxide found were small and the error incurred by considering the total iron content of the slag as ferrous oxide is negligible. This procedure was adopted in the calculation of mole fractions, where the total iron oxides are tabulated as Fe_TO.

The reaction concerned in the establishment of equilibrium between the gas phase, the slag and the metal crucible may be expressed as:

$$H_2O_{(gas)} + Fe_\gamma = H_{2(gas)} + FeO_{(slag)} \quad \ldots\ldots\ldots(1)$$

The equilibrium constant for this reaction may be written:

$$K = \frac{\alpha_{FeO} \cdot p_{H_2}}{p_{H_2O}} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

where p_{H_2} and p_{H_2O} are the partial pressure of hydrogen and steam respectively. The value of the constant was calculated from the available thermodynamic data. The standard state chosen was pure liquid ferrous oxide in equilibrium with pure iron in the γ form.

Darken and Gurry[10] have determined the partial pressures of CO and CO_2 in equilibrium with pure iron and wüstite over the temperature range 1 400–1 600° C. From their data, applying the correction for the change from δ to γ iron,

$$FeO_{(slag)} + CO_{(gas)} = Fe\gamma + CO_{(gas)} \quad \ldots\ldots\ldots(3)$$
$$\Delta G^\circ = -12\,080 + 9{\cdot}868T \text{ cal/mol}$$

where ΔG° is the free-energy change and T the absolute temperature. The standard free-energy for the water gas reaction is[11]:

$$CO_{2(gas)} + H_{2(gas)} = CO_{(gas)} + H_2O_{(gas)}$$
$$\Delta G^\circ = +6\,383 - 6{\cdot}222T \text{ cal/mol} \quad \ldots\ldots(4)$$

adding

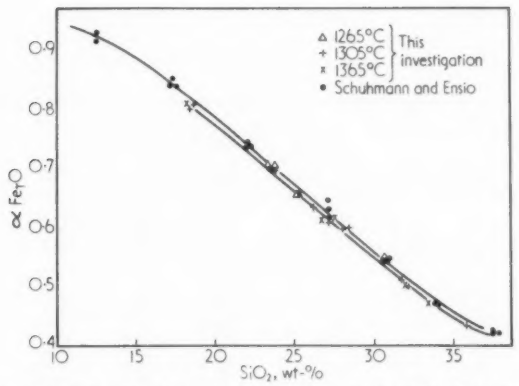
$$FeO_{(slag)} + H_{2(gas)} = Fe_\gamma + H_2O_{(gas)}$$
$$\Delta G^\circ = -5\,697 + 3{\cdot}646T \text{ cal/mol} \quad \ldots\ldots(5)$$

hence $$\Delta G^\circ = -RT\ln\frac{\alpha_{Fe} \cdot p_{H_2O}}{\alpha_{FeO} \cdot p_{H_2}}$$

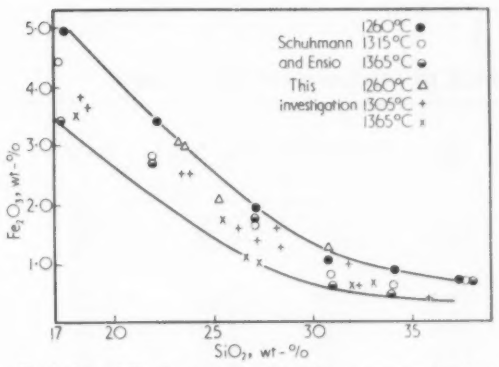
Re-arranging and substituting for ΔG° etc.:

$$\log \alpha_{FeO} = \log\frac{(p_{H_2O})}{(p_{H_2})} - \frac{1\,246}{T} + 0{\cdot}7969 \quad \ldots\ldots(6)$$

For each run the partial pressure of steam was determined from the temperature of the saturator tank and the steam tables. The partial pressure of hydrogen in the mixture was evaluated next from the



2 *The influence of composition on the activity of* Fe_TO *in the binary slags*



3 *Variation of* Fe_2O_3 *content with silica concentration in the binary melts*

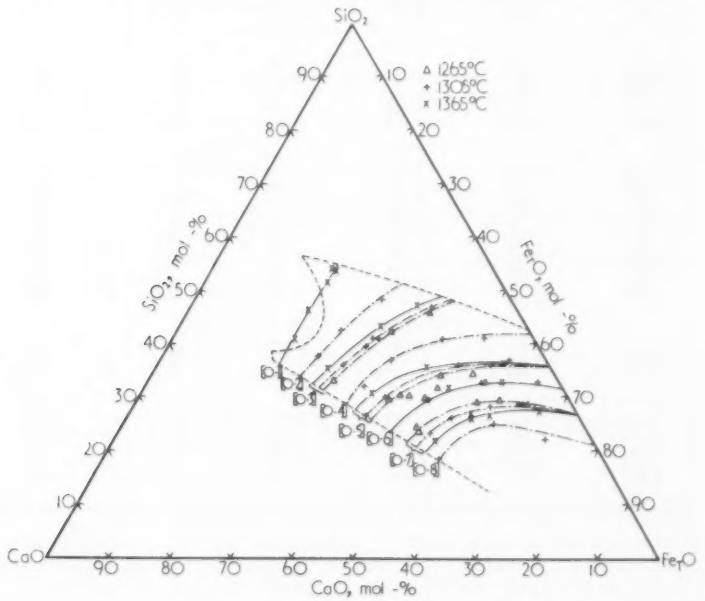
H_2/A ratio of the cylinder gas. These values were substituted in equation (6) and the activity was calculated at the temperature of the melt. If the recorded saturation temperature was in error by 0·05° C at 60° C the error in the estimated value of α_{Fe_TO} is 0·0022. The error in α_{Fe_TO} corresponding to a 0·05° C error decreases with temperature and is only 0·0011 at 36° C. A change of 5·0° C in the crucible temperature at 1 300° C is equivalent to a variation of 0·0048 in the activity at $\alpha_{Fe_TO} = 0·8$ and of 0·0013 at $\alpha_{Fe_TO} = 0·2$.

The calculated values of α_{Fe_TO} are plotted against wt-%SiO_2 in Fig. 2 and are compared with the values obtained by Schuhmann and Ensio.[1] The present results are best fitted by a curve drawn parallel to the mean line through their data and located at a slightly higher iron oxide content for any given value of α_{Fe_TO}. The deviation between the two curves is equivalent to a difference of 0·009 in α_{Fe_TO} or of 0·48% in the estimated value of SiO_2, and is well within the experimental error.

In addition to the experiments described above, a number of runs were made on melts in this system with the second form of apparatus. During the subsequent experiments on the multi-component slags, occasional binary melts were inserted to confirm that the gas mixture was saturated and that the apparatus was functioning correctly. The results obtained were consistent with those from the original apparatus and these melts are designated *BA* in the Table II. The mean line in Fig. 2 is based on all the results obtained for the binary slags.

Examination of the results obtained at the three temperatures studied reveals no significant trend and confirms the observation of Schuhmann and Ensio[1] that the activity of ferrous oxide is independent of temperature within the range studied.

The variation of ferric oxide content of the binary slags is compared with the results of the above workers in Fig. 3. Smooth curves have been drawn through their data, the upper curve representing the mean ferric oxide contents found at 1 265° C and the lower curve for 1 365° C. The present results, with



4 *Ferrous oxide iso-activity lines at 1 265° C, 1 305° C, and 1 365° C*

TABLE III Analyses of FeO–CaO–SiO_2 melts

Melt No.	Temperature, °C	p_{H_2O}/p_{H_2}	a_{Fe_TO}	Analysis Wt-% FeO	Fe_2O_3	SiO_2	CaO	Mol-% Fe_TO	SiO_2	CaO
CA 1	1 309	0·787	0·804	70·8	3·4	19·4	6·4	70·2	22·0	7·8
CA 2	1 308	0·788	0·804	62·7	2·8	22·3	12·2	60·6	24·9	14·5
CA 3	1 304	0·785	0·798	57·5	2·9	16·5	23·1	54·9	18·0	27·1
CA 4	1 260	0·726	0·700	65·8	2·7	25·2	6·3	64·1	28·3	7·6
CA 5	1 260	0·726	0·700	61·7	2·3	26·7	9·3	59·2	29·7	11·1
CA 6	1 259	0·720	0·693	58·7	2·0	26·2	13·1	55·6	28·9	15·5
CA 7	1 260	0·729	0·703	51·9	2·1	22·1	23·9	48·5	23·8	27·7
CA 8	1 260	0·729	0·703	51·4	2·2	22·1	24·3	48·1	23·8	28·1
CA 9	1 305	0·687	0·698	67·9	2·0	24·6	5·5	65·6	27·8	6·6
CA10	1 305	0·687	0·698	61·4	1·5	25·8	11·3	58·1	28·5	13·4
CA11	1 306	0·681	0·693	56·9	1·3	24·1	17·7	53·0	26·3	20·7
CA12	1 303	0·686	0·697	54·7	1·6	21·5	22·2	50·9	23·3	25·8
CA13	1 361	0·636	0·688	69·4	1·4	24·3	4·9	66·6	27·5	5·9
CA14	1 367	0·636	0·693	62·6	1·0	24·6	11·8	58·8	27·2	14·0
CA15	1 360	0·636	0·687	59·2	1·7	24·5	14·6	55·9	26·9	17·2
CA16	1 360	0·636	0·687	59·3	1·8	23·9	15·0	56·2	26·2	17·6
CA17	1 363	0·638	0·692	56·1	1·8	19·7	22·4	52·4	21·5	26·1
CA18	1 262	0·622	0·601	58·4	1·4	30·1	10·1	55·0	33·1	11·9
CA19	1 262	0·622	0·601	51·3	1·4	29·7	17·6	47·5	32·1	20·4
CA20	1 266	0·622	0·604	50·9	1·2	27·7	20·2	46·8	29·9	23·3
CA21	1 306	0·597	0·607	66·8	1·3	29·1	2·8	63·9	32·7	3·4
CA22	1 307	0·597	0·608	58·5	1·4	29·5	10·6	55·1	32·4	12·5
CA23	1 304	0·594	0·603	51·9	1·0	27·3	19·8	47·6	29·5	22·9
CA24	1 368	0·554	0·604	61·4	1·3	29·8	7·5	58·0	33·1	8·9
CA25	1 370	0·554	0·605	53·3	1·4	29·4	15·9	49·6	31·9	18·5
CA26	1 370	0·554	0·605	50·8	1·8	27·4	20·0	47·2	29·6	23·2
CA27	1 307	0·531	0·542	49·6	0·9	27·9	21·6	45·2	30·0	24·8
CA28	1 259	0·526	0·518	51·1	1·2	31·4	16·3	47·2	34·0	18·8
CA29	1 265	0·526	0·522	57·5	1·4	32·3	8·8	52·3	34·3	13·4
CA30	1 265	0·527	0·522	47·7	1·7	28·0	22·6	44·0	30·0	26·0
CA31	1 264	0·526	0·521	46·3	1·5	28·3	23·9	42·5	30·2	27·3
CA32	1 258	0·525	0·506	44·4	1·8	27·7	26·1	40·9	29·4	29·7
CA33	1 305	0·489	0·497	60·5	1·3	33·1	5·1	56·8	37·1	6·1
CA34	1 304	0·492	0·500	55·1	1·0	33·0	10·9	51·2	36·1	12·7
CA35	1 304	0·484	0·492	52·6	1·6	33·1	12·7	49·2	36·0	14·8
CA36	1 309	0·490	0·500	43·7	1·8	28·3	26·2	40·2	30·0	29·8
CA37	1 310	0·492	0·503	41·8	1·6	25·4	31·2	38·2	26·6	35·2
CA38	1 359	0·463	0·500	60·1	0·7	33·1	6·1	56·1	36·6	7·3
CA39	1 357	0·463	0·499	47·7	1·5	33·0	17·8	44·1	35·5	20·4
CA40	1 361	0·462	0·500	41·6	1·2	29·4	27·8	37·6	31·0	31·4
CA41	1 307	0·445	0·454	45·3	1·6	34·9	18·2	41·8	37·3	20·9
CA42	1 308	0·447	0·456	44·1	1·3	34·9	19·7	40·3	37·1	22·6
CA43	1 307	0·413	0·422	54·3	1·3	37·5	6·9	50·9	41·0	8·1
CA44	1 307	0·381	0·388	48·2	1·0	38·1	12·7	44·2	41·1	14·7
CA45	1 306	0·408	0·415	41·5	1·5	35·0	22·0	38·0	37·1	24·9
CA46	1 308	0·389	0·396	39·6	1·5	30·4	28·5	36·0	31·9	32·1
CA47	1 306	0·329	0·335	41·7	0·9	39·9	17·5	37·7	42·4	19·9
CA48	1 262	0·312	0·302	43·0	0·8	43·1	13·1	39·0	46·0	15·0
CA49	1 262	0·312	0·302	39·1	0·8	40·2	19·9	35·1	42·4	22·5
CA50	1 260	0·312	0·301	33·9	0·9	32·1	33·1	30·1	33·2	36·7
CA51	1 305	0·300	0·306	43·4	0·8	43·8	12·0	39·4	46·8	13·8
CA52	1 306	0·301	0·306	36·7	0·7	39·2	23·4	32·7	41·0	26·3
CA53	1 306	0·302	0·308	36·7	0·6	37·8	24·9	32·6	39·6	27·8
CA54	1 307	0·301	0·306	34·1	1·2	34·7	30·0	30·6	36·0	33·4
CA55	1 360	0·275	0·298	41·6	0·5	44·4	13·5	37·4	47·3	15·3
CA56	1 355	0·276	0·297	37·2	0·5	41·5	20·8	33·0	43·6	23·4
CA57	1 360	0·276	0·299	31·9	0·6	34·4	33·1	28·0	35·5	36·5
CA58	1 298	0·199	0·201	34·3	0·5	46·6	18·6	30·5	48·7	20·8
CA59	1 307	0·199	0·202	30·4	0·6	41·3	27·7	26·7	42·7	30·6
CA60	1 302	0·199	0·201	29·0	0·4	37·3	33·3	25·8	37·9	36·3
CA61	1 360	0·094	0·102	23·2	0·6	52·6	23·6	20·3	53·9	25·8
CA62	1 362	0·094	0·102	22·6	0·4	53·0	24·0	19·6	54·1	26·3
CA63	1 370	0·094	0·102	23·2	0·4	50·6	25·8	20·1	51·6	28·3
CA64	1 368	0·093	0·102	22·6	0·4	45·7	31·3	19·5	46·4	34·1
CA65	1 366	0·095	0·103	23·2	0·5	40·6	35·7	20·0	41·2	38·8

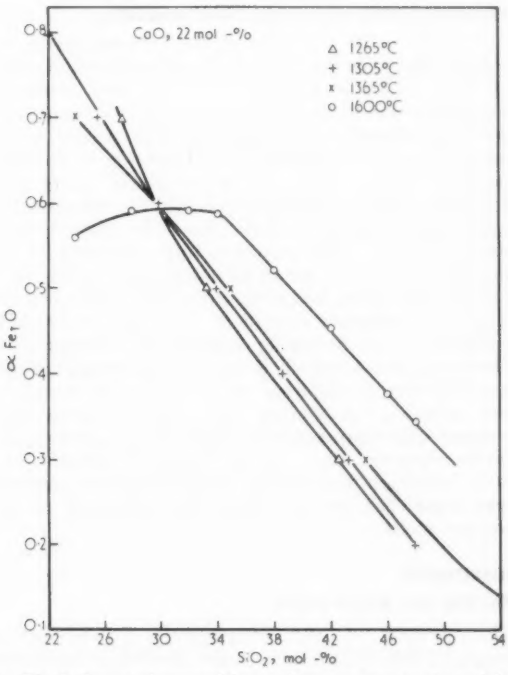
one exception, fall within the range so described and thus support the assertion that the method of sampling the slags was satisfactory. The scatter in the isothermal results is small and within the limits of experimental accuracy. The general trend is a decrease in ferric oxide content with increasing temperature. Within the composition range studied this variation is greater with small silica contents.

The system FeO–SiO_2–CaO

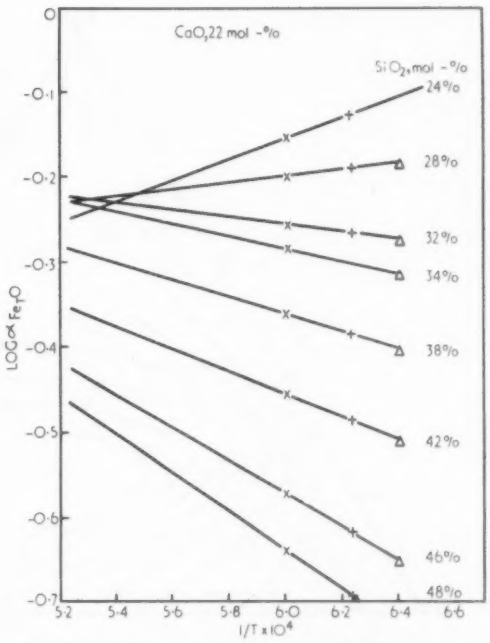
The phase equilibria in the silica-rich portion of this system were reported some years ago.[12] More recently data were published for the iron-oxide-rich region, thus establishing the complete liquidus surface at temperatures up to 1 500° C.[13] The ferric oxide contents ranged from 0·5% at about 10%FeO to 17·5% adjacent to the FeO–CaO binary edge. Consequently, the phase diagram cannot be regarded as a true ternary. However, the diagram can be employed to describe the liquidus boundaries at the present experimental temperatures since the melts were fused in iron crucibles in both investigations.

Iron–calcium silicate melts were equilibrated with H_2–H_2O–A mixtures and iron crucible at 1 265°, 1 305°, and 1 365° C. The slags in the high-silica region were expected to be more viscous than those richer in iron oxide, but no difficulty was encountered in obtaining reproducibility at the 0·1 FeO activity level at 1 365°. However, attempts to locate the 0·1 activity at 1 305° C and the 0·2 line at 1 265° C were inconsistent even after 8-h runs and these are not included in the final plot.

The data for slags for which complete analyses are available are recorded in Table III. Iso-activity contours for the three experimental temperatures are



5 *The influence of composition and temperature on the activity of* Fe_xO



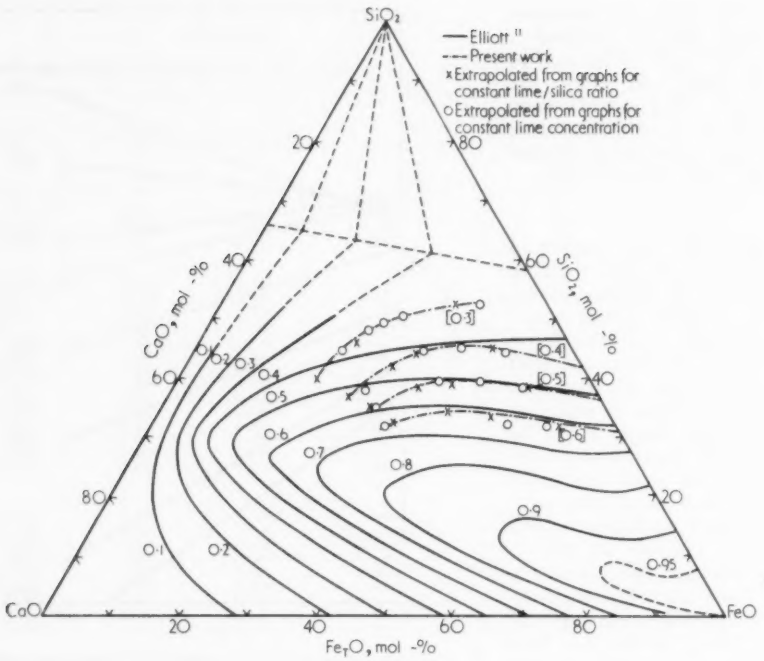
6 *Variation of the activity of ferrous oxide with temperature*

shown in Fig. 4. In the construction of the curves allowance was made for the small variations in activity and temperature in each series of experimental determinations. The 0·5 contour at 1 265° C was extrapolated graphically from the results, which gave activities between 0·51 and 0·52. The intercepts along the binary edge are taken from Fig. 2. The contours indicate an increase in the activity of ferrous oxide with increasing lime concentration, in line with the observations at 1 600° C.[2,6]

The outstanding feature of the ternary results is the marked variation of the activity of ferrous oxide with temperature, whereas no temperature dependence could be detected in the ferrous silicate binary melts. The exception to this observation is the 0·6 iso-activity line. There is a small scatter of the results at this activity level but, within the limits of the experimental accuracy, the points representing the melts at the three temperatures can be fitted by a single line. When the activity of ferrous oxide at 1 265° C is less than 0·6 (i.e. at lower FeO contents) the activity increases with temperature. However, when the 1 265° C activity is greater than 0·6 the temperature dependence is of opposite sign.

Derivation of the iso-activity plot at 1 600°C

Extrapolation of experimental data to temperatures outside the range investigated is of doubtful validity. However, this procedure has been adopted with the present results to obtain a comparison with the available data from other sources. Values of α_{Fe_xO} at the three temperatures studied were derived from Fig. 4 and were plotted against the molar concentration of silica at intervals of 8 mol-%. Smooth curves were drawn through the three sets of points and were made to intersect at the 0·6 activity value. Similar curves were derived at constant ratios of lime



7 *Ferrous oxide iso-activity lines at 1 600°C*

to silica between 1 : 4 and 1 : 2. The value of α_{Fe_TO} at each temperature for small increments of silica or ferrous oxide concentration was obtained from these curves and was plotted against $1/T°K$. A typical pair of graphs is reproduced in Figs. 5 and 6. Inspection of the second set of plots revealed no consistent deviation from linearity between the points for the three temperatures and the activity of 1 600° C was therefore obtained by linear extrapolation of the experimental data. This treatment assumes that the relative partial molar heat content of ferrous oxide is independent of temperature.

The iso-activity contours for values of α_{Fe_TO} from 0·3 to 0·6 at 1 600° C were derived from the extrapolated data and are shown in Fig. 7. The curves were extended to the appropriate points on the FeO–SiO_2 binary side on the assumption that α_{Fe_TO} is independent of temperature for the binary slags. The activity curves obtained by Elliott[2] are also shown for comparison. In the latter case the intercepts on the binary side had been adjusted from Schuhmann and Ensio's results[1] by assuming a linear relationship between $\log\alpha_{Fe_TO}$ and the reciprocal of the temperature in degrees absolute. If no such correction had been made it is apparent that the two sets of data would be consistent for lime concentrations of 0–20 mol-%. With higher lime contents the present results indicate that the positive deviation at low iron oxide contents is less than the previous work suggested. The location of the activity contours along the pseudobinary line $CaO/SiO_2 = 1 : 1$ must be considered less accurately located than the other data, since this line approaches fairly closely to the 1 300° C liquidus isothermal for the ternary system. However, the iso-activity contours drawn through the experimental points would have to be moved considerably to bring the 1 600° C plot coincident with the previous work; such adjustments would not be consistent with the present experimental data. The discrepancy is probably due to the magnesia contained in the melts used in the earlier work.

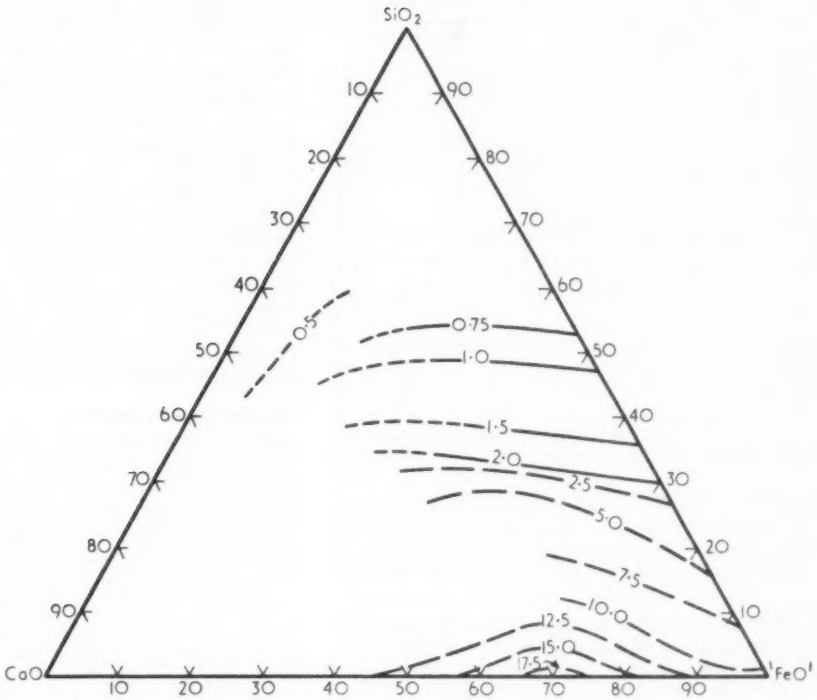
Variation of ferric oxide content with composition

The ferric oxide contents of the ternary melts fell within the range 0·4% to 3·0%. Examination of the analysis in Table III indicates a general tendency for a reduction in the concentration of this component with increasing temperature, but the scatter is too large to permit a quantitative evaluation of the temperature effect. The results for all the melts were therefore plotted together and Fig. 8*b* indicates the approximate position of the lines of constant ferric oxide content. The concentrations reported at the liquidus surface are given for comparison in Fig. 8*a*.[13] Comparison of the two diagrams shows that when the silica concentration exceeds 30 wt-% the ferric oxide content is not markedly affected by temperature. However, with lower silica contents the present results are appreciably different from the values found at the liquidus. A similar variation of ferric oxide content with temperature was also found in the binary melts when the silica concentration fell below about 30% although the actual temperature dependence was somewhat greater than that observed in the ternary melts.

DISCUSSION

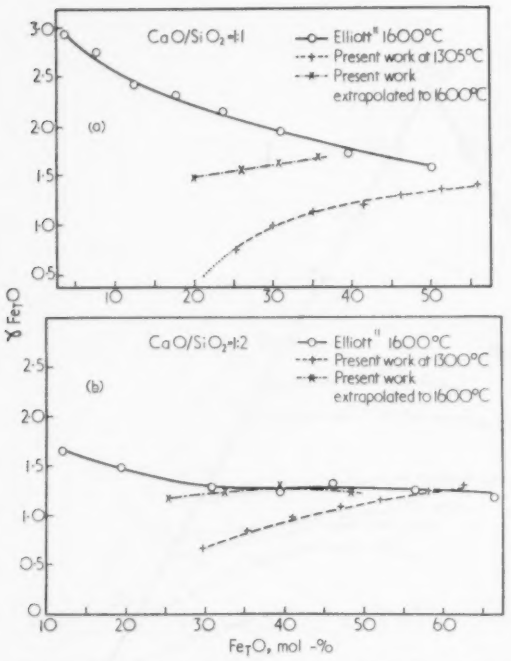
The FeO–SiO_2 binary system

The absence of any temperature dependence of α_{Fe_TO} in the composition range studied is surprising in view of the significant temperature effect found when lime was added to the melts. In fact, the



8a *Variation of* Fe_2O_3 *content with composition at the liquidus temperatures in the ternary system* (after *Allen and Snow*[13])

8b *Variation of* Fe_2O_3 *content with composition in the ternary melts*



9a and **b** *Variation of the activity coefficient of ferrous oxide with composition in the ternary melts*

reverse tendency would normally be expected on the basis of the free energies of formation of the respective ferrous and calcium silicates. Furthermore, the insensitivity of α_{Fe_TO} to temperature implies that the heat of formation of ferrous oxide is zero. This is not in accordance with the heats of formation estimated by Rey[14] and Turkdogan and Pearson.[6] The curve derived by Rey was based on the regular solution concept. This approach has been criticized in its application to silicate-rich melts. Turkdogan and Pearson estimated the temperature dependence by plotting data from various sources for α_{Fe_TO} in the range 1 315–1 650° C. Some of their high-temperature data were obtained by extrapolating iso-activity curves for multi-component slags to the binary side and hence are subject to appreciable error. The change in activity estimated by both methods over the temperature range studied in this programme is greater than the estimated experimental error and, if real, should have been detected with the present technique at the higher silica concentrations.

The activity curve for MnO *v.* concentration in binary silicate melts exhibits a small inflection for compositions more basic than the orthosilicate, but the activity coefficient is less than unity.[8] The present results and those of Schuhmann and Ensio[1] indicate a positive deviation from ideality for α_{Fe_TO} in the corresponding ferrous silicates. It is suggested that this is predominantly a function of the ferric ion concentration. The ratio Fe^{+++}/Fe^{++} increases rapidly from the orthosilicate to the wüstite liquidus (Fig. 3) and is approximately a linear function of the total iron content of the melt. A progressive increase in the number of triple-charged ions, with a simultaneous increase in the number of vacant cation sites, will decrease the entropy of mixing and positive deviations from ideality are probable. It is anticipated that in the stoichiometric $FeO–SiO_2$ system the activity of ferrous oxide maintains a negative deviation from ideality throughout the concentration range and is located closer to that recorded for α_{M_nO} in the binary silicate melts; i.e. the form of the activity curve is a consequence of the chosen standard state.

The tendency towards immiscibility in the FeO-rich silicate melts is not unique. Thus extensive immiscibility occurs in the iron-oxide-rich regions of the systems $FeO–CaF_2$, $FeO–3CaO \cdot P_2O_5$, and the $FeO–3Na_2O \cdot P_2O_5$ whereas CaO, MgO, and MnO are completely miscible in fluoride and phosphate melts. White[15] suggests that this is due to the covalent nature of the Fe–O bond, it is probable that this is also a function of the Fe^{+++}/Fe^{++} ratio.

The effect of lime additions

The pronounced positive deviations from ideal behaviour observed at 1 600° C[3] along the $FeO–2CaO \cdot SiO_2$ join is commonly attributed to the tendency for association between Ca^{++} ions and the silicate-complex ions and also between Fe^{++} and O^{--} ions. This may be expressed in the following form:

$$(2CaO \cdot SiO_2) + (2FeO \cdot SiO_2) = 2(CaO \cdot SiO_2) + 2(FeO) \quad \ldots\ldots(7)$$

With lime concentrations in excess of this join the activity of ferrous oxide decreased due to association between Ca^{++} and Fe^{+++} ions,[5, 16] i.e. under these conditions the ferric ions must presumably function as anion complexes of the $Fe_2O_4^{--}$ type. This tendency has been clearly demonstrated by Richardson[17] who showed that the modifying effect of calcium ions is apparent immediately the composition is displaced from the $FeO–SiO_2$ binary side of the ternary system and is progressive up to the composition at which all the silicate groups have been converted to SiO_4^{4-} units. Thereafter α_{Fe_TO} increases only slowly with increasing basicity and ultimately decreases due to ferrite association.

At the present experimental temperatures the pattern of behaviour is rather different. Under these conditions α_{Fe_TO} exhibits a positive deviation from Raoultian behaviour at moderate silica contents, but this changes to a negative deviation as the silica concentration is increased. This is brought out more clearly in Fig. 9 where γ_{Fe_TO} is plotted against N_{Fe_TO} for CaO/SiO_2 ratios of 1 : 1 and 1 : 2. Furthermore, if the 0·1 and 0·2 iso-activity lines in Fig. 4 are extrapolated to higher lime contents similar behaviour is suggested at the 2 : 1 ratio. Thus, the shape of the activity/composition curve is similar to that found for the binary melts, but the change from positive to negative deviation occurs at increasing silica contents as the lime concentration is raised. The extrapolated activity coefficient lines for 1 600° C indicate that a positive deviation is maintained at this temperature throughout the composition range studied. Thus, as the temperature is raised in the silica-rich melts the system apparently changes from a condition typical of association between unlike species to one with a tendency to unmixing. The ferric oxide contents of these melts are low and are

TABLE IV Comparison of experimental and calculated activities

No.	Ratio CaO/SiO_2	$N_{Fe^{++}}$	$N_{Ca^{++}}$	N_{SiO_2}	$N_{O^{--}}$	$\gamma_{Fe_TO(B)}$	α_{Fe_TO} — 1 365° C			α_{Fe_TO} — 1 600° C		
							A (Experimental)	B (Calculated)	C	D (Experimental)	E (Calculated)	F
1	1 : 1	0·335	0·665	0·665	0·335	0·72	0·07	0·24	0·19	0·30	0·48	0·27
2	1 : 1	0·415	0·585	0·585	0·415	0·77	0·26	0·31	0·30	0·40	0·53	0·41
3	1 : 1	0·466	0·534	0·534	0·466	0·81	0·35	0·36	0·38	0·50	0·56	0·53
4	1 : 1	0·512	0·488	0·488	0·512	0·86	0·43	0·41	0·45	0·60	0·59	0·60
5	2 : 3	0·430	0·570	0·855	0·145	0·71	0·16	0·15	0·15	0·30	0·32	0·24
6	2 : 3	0·531	0·469	0·707	0·293	0·71	0·32	0·26	0·31	0·40	0·43	0·46
7	2 : 3	0·589	0·411	0·618	0·382	0·74	0·41	0·31	0·40	0·50	0·46	0·56
8	2 : 3	0·621	0·379	0·567	0·433	0·78	0·47	0·36	0·46	0·60	0·50	0·62
9	1 : 2	0·598	0·402	0·816	0·184	0·72	0·30	0·18	0·25	0·40	0·30	0·39
10	1 : 2	0·674	0·326	0·652	0·348	0·72	0·42	0·28	0·39	0·50	0·39	0·54
11	1 : 2	0·736	0·264	0·527	0·473	0·82	0·54	0·40	0·52	0·60	0·50	0·65
12	1 : 4	0·793	0·207	0·756	0·204	0·72	0·25	0·17	0·25	0·40	0·24	0·33
13	1 : 4	0·840	0·160	0·639	0·361	0·73	0·36	0·28	0·37	0·50	0·34	0·45
14	1 : 4	0·882	0·118	0·471	0·529	0·87	0·46	0·46	0·54	0·60	0·52	0·60

not significantly altered by increasing temperature. Hence, the behaviour cannot be attributed to this component.

Richardson has demonstrated that mixtures of ions may behave ideally although their activities deviate considerably from Raoultian behaviour.[17] On this basis, assuming ideal mixing of the binary silicates he has calculated the 'ideal' activity curves for ferrous oxide in FeO–CaO–SiO_2 ternary melts.[7] The calculated curves correlate well with the experimental data of Chipman *et al.* for metasilicate melts at 1 600° C, but indicate higher activities at the orthosilicate join. The available thermodynamic data is inadequate to justify re-calculation of the ideal mixing behaviour at the present experimental temperatures. However, if it is assumed that the activities in CaO–SiO_2 binary mixtures do not vary markedly with temperature, it is at once apparent that the activity of ferrous oxide approaches the 'ideal mixing' curves with increasing temperature.

The reaction described in equation (7) could satisfy the experimental observations on the above basis. Approximate evaluation of the free energy change for this reaction indicates that the equilibrium is displaced progressively towards the right with increasing temperature; i.e. the ratio SiO_4^{4-}/SiO_3^{2-} decreases with the rising temperature, accompanied by a simultaneous increase in the $(Fe^{2+}–O^{2-})$ groups. Support for this premise is forthcoming from other data. Thus, $CaO \cdot SiO_2$ groups have been identified in liquid silicates[18] whereas the corresponding ferrous silicate is not stable even in the solid state. There is strong evidence that the type of bonding present in solid silicate mixtures containing FeO is retained in the liquid.[19] Kheinman has shown that the electrical conductivity of mixed calcium and ferrous orthosilicates decreases linearly with decreasing $2FeO \cdot SiO_2$ content and approaches zero as the concentration of this component approaches zero.[20]

The maximum in the γ_{Fe_TO}/N_{Fe_TO} curve is expected to occur at, or close to, the orthosilicate join. With more basic liquids all the silica exists as discrete SiO_4^{4-} anions and the ferric ions are then more readily able to function as oxyacid groups. This is indicated by the rapid increase in ferric iron content with increasing basicity, compared to the slow variation between silica saturation and the orthosilicate. The maximum is actually positioned at the 0·6 iso-activity contour, which is located somewhat below the orthosilicate join and corresponds closely to the wüstite liquidus boundary. The agreement with the latter may be fortuitous, but it suggests that the behaviour of the liquid silicates is closely related to the behaviour in the solid state.

Derivation of an ionic expression for the activity of ferrous oxide

One of the primary objectives in the initiation of this research programme was the derivation of one or more equations which would facilitate the calculation of α_{Fe_TO} at any given slag composition and temperature above the liquidus surface. Several ionic equations have been produced in recent years, which have been applied with varying success to steelmaking reactions.[21, 22, 23, 24]

Flood, Forland, and Grjotheim[25] have recently derived an expression relating the activity of ferrous oxide to the composition in basic slags, the formula containing terms for each of the exchange equilibria in which FeO can partake. The formula ceases to function when the orthosilicate composition is reached, since all the O^{2-} ions are then attributed to the SiO_4^{4-} tetrahedra. The present results indicate, however, that the SiO_3^{2-} ion is probably stable in the presence of lime and ferrous oxides at compositions corresponding to, and probably slightly more basic than, the orthosilicate join. If the equation is modified on the basis of the existence of SiO_3^{2-} ions it is still inadequate for the evaluation of the present results, since it does not admit values of γ_{Fe_TO} less than 1. Their equation was accordingly adjusted to accommodate this deviation by incorporating the activity coefficient of ferrous oxide at the binary FeO–SiO_2 for the same silica concentration as that of the ternary melt considered. This is an empirical correction and will cease to be applicable as the lime concentration approaches zero. The modified formula is:

$$\boldsymbol{R}T\ln\alpha_{Fe_TO} = \boldsymbol{R}T\ln N_{Fe}N_O + \boldsymbol{R}T\ln\gamma_{Fe_TO}\ (binary) + xN'_{Ca} \cdot N'_{SiO_2} \quad \ldots\ldots(8)$$

Flood evaluated the numerical quotient (x) of his equation from the ΔG^0 of the reaction between the mixed silicates. These values are not markedly affected by temperature and the binary activity coefficient appears to be independent of the temperature. Thus, at any given composition the calculated activity will decrease with increasing temperature. The experimental findings show the reverse effect with $\alpha_{Fe_TO} < 0{\cdot}6$ and the numerical quotient must be

increased as the temperature is raised to obtain comparative values between the actual and calculated activities. Assuming values for x of 8 000 and 15 000 at 1 365° C and 1 600° C respectively, the calculated activities are listed in columns B and E of Table IV. The experimental values are shown for comparison in columns A and D. The agreement is poor and decreases with increasing temperature. In both cases the equation predicts a more gradual increase in activity with increasing basicity than was found in the experimental work.

A much closer approach to the actual activity values can be obtained if the above equation is modified to:

$$\boldsymbol{R}T\ln\alpha_{FeO} = \boldsymbol{R}T\ln N_{Fe}N_{O(B)} + \boldsymbol{R}T\ln\gamma_{FeO(B)} + xN'_{Fe}N'_{Ca}N'_{SiO_3} \quad \ldots\ldots(9)$$

Assuming values for x of 19 000 at 1 365° C and 30 000 at 1 600° C the calculated activity values are shown in columns C and F of Table IV. The agreement with the experimental values is much closer at both temperatures. The compositions considered cover the range of silica concentration from slightly more basic than the orthosilicate join to within a few per cent of the metasilicate line. The equation ceases to apply beyond the latter limit since the oxygen-ion fraction, assuming silica is present as SiO_2^{2-}, then becomes zero, and a silicate complex of lower oxygen content must be considered. Compositions more basic than the 0·6 isoactivity line are excluded since the effect of temperature variation was not closely ascertained beyond that range. Furthermore, the ferric oxide content of the acid slags considered was low and could be treated to a first approximation as ferrous oxide.

No quantitative conclusions of the ionic behaviour can be drawn from this treatment since the equation which best fits the results is empirical. It is possible that the numerical quotient is some function of the entropy of mixing; it is notable that in its present form it has a value of zero as the FeO and CaO concentrations fall to zero.

Work is now proceding to evaluate the effect on α_{FeO} of additional components added to FeO–CaO–SiO_2 basis slags. Preliminary results indicate that at low concentrations MnO lowers the activity coefficient markedly. With concentrations up to at least 8 mol-% equation (9) fits the results reasonably well if the Mno is treated as an inert diluent.

CONCLUSIONS

(1) The data obtained for the activity/composition curve for binary ferrous silicate melts was found to agree, within the limits of the experimental error, with that found by Schuhmann and Ensio. The activity appears to be independent of the temperature within the range 1 265–1 365° C.

(2) In the presence of lime and silica the activity of ferrous oxide is markedly temperature dependent. The activity coefficient increases with increasing temperature for melts more acid than the 0·6 isoactivity contour. The reverse effect is found for the more basic melts. Linear extrapolation of the results for the silica-rich melts up to 1 600° C gives close agreement with the results of Chipman *et al.* with lime concentrations of up to 20 mol-%. At higher lime contents the activity coefficient is lower than that previously reported.

(3) The experimental results can be reproduced fairly closely by an ionic expression containing empirical constants. Preliminary results suggest that this equation can be applied to more complex melts. It is apparent that no simple ionic treatment can account for the behaviour of acid slags.

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REFERENCES

1. R. Schuhmann and P. J. Ensio: *Trans. AIME*, 1951, **191,** 401–411; *J. Met.*, 1951, **3,** May.
2. J. F. Elliott: *Trans. AIME*, 1955, **203,** 485–488; *J. Met.*, 1955, **7,** March.
3. C. R. Taylor and J. Chipman: *Trans. AIME*, 1943, **154,** 228–245; *Metals Technology*, 1942, **9,** Tech. Publ. no.1499.
4. T. B. Winkler and J. Chapman: *Trans. AIME*, 1946, **167,** 111–133; *Metals Technology*, 1946, **13,** Tech. Publ. no. 1987.
5. K. L. Fetters and J. Chipman: *Trans. AIME*, 1941, **145,** 95–107; *Metals Technology*, 1941, **8,** Tech. Publ. no.1316.
6. E. T. Turkdogan and J. Pearson: *JISI*, 1953, **173,** 217–223..
7. F. D. Richardson: *Trans. Farad. Soc.*, 1956, **52,** Oct., 1312–1324.
8. H. B. Bell, A. B. Murad, and P. T. Carter: *Trans. AIME*, 1952, **194,** 718–722; *J. Met.*, 1952, July.
9. C. Bodsworth and W. R. Maddocks: *JISI*, 1957, **185,** 75–82.
10. L. S. Darken and R. W. Gurry: *J. Am. C. S.*, 1946, **68,** 798–816.
11. Selected values of chemical thermodynamics, Nat. Bureau of Standards, 1948.
12. N. L. Bowen, J. F. Schairer, and E. Posnjak: *Amer. J. Sci.*, 1933, 5th series, **26,** 193–284.
13. W. C. Allen and R. B. Snow: *J. Am. Ceram. Soc.*, 1955, **38,** 264–280.
14. M. Rey: Symposium on physical chemistry of melts, Inst. of Mining and Metallurgy, 63–70, 1953.
15. J. White: Ceramics: a symposium, Br. Ceram. Soc., 94–162, 1953.
16. H. R. Larson and J. Chipman: *Trans. AIME*, 1954, **200,** 759–762; *J. Met.*, 1954, **6,** June.
17. F. D. Richardson: Symposium on Physical Chemistry of Melts, Inst. of Mining and Metallurgy, 75–95, 1953.
18. O. A. Esin and B. M. Lipinskikh: *Izvest. Akad. Nauk. USSR Otdelenie Tekn. Nauk*, 1954, (2), 60–66.
19. P. Röntgen, H. Winterhager, and R. Kammel: *Z. Erzbergb und Metallhüttenwesen*, 1956, **9,** (5), 207–214.
20. A. S. Kheinmann: *Bull. de l'Académie des Sciences de l'URSS Classe des Sci. Tech.*, 1946, 1439.
21. P. Herasymenko: *Trans. Farad. Soc.*, 1938, **34,** 1245–1257.
22. P. Herasymenko and G. E. Speight: *JISI*, 1950, **166,** 169–183.
23. M. Temkin: *Acta Phys. Chim. URSS*, 1945, **20,** (4), 411–420.
24. H. Flood and K. Grjotheim: *JISI*, 1952, **171,** 64–70.
25. H. Flood, T. Førland, and K. Grjotheim: Symposium on physical chemistry of melts, Inst. of Mining and Metallurgy, 46–59, 1953.

Carbides in annealed and quenched high-speed steels

T. Malkiewicz, Z. Bojarski, and J. Foryst

SYNOPSIS

Carbides in annealed and quenched W–Cr–V *high-speed steels have been studied by the electrolytic extraction method, by chemical analysis of residues, and by X-ray powder analysis. It was found that the composition of the matrix of these annealed and quenched steels is very similar. The differences consist in the composition and the amount of carbides.*

The predominant carbide in both types of steel is M_6C, which differs in chemical composition according to the type of steel. The presence of $M_{23}C_6$, M_7C_3, and MC carbides has also been established; $M_{23}C_6$ and M_7C_3 dissolve during the austenitizing of steel up to 1 100° C. Intensive solution of tungsten and vanadium in the matrix begins at about 1 200° C. 1606

THE WORK of Westgren and his co-workers[1–3] on the structure of iron–tungsten and iron–chromium carbides is of fundamental importance to the constitution of high-speed steels. Further investigations on the structure of iron–tungsten carbides were carried out by Umansky and Chebotarev[4] and Chebotarev.[5] The behaviour of carbides during heat-treatment of alloy steels, including high-speed steels, was studied by Krainer,[6] Goldschmidt,[7–10] Kuo,[11, 12] Cohen *et al.*,[13, 14] Papier,[15] Gulayev,[16] and Arkharov *et al.*[17]

The predominant carbide in high-speed steels of the W–Cr–V type is agreed to be the iron–tungsten carbide M_6C, where M = W, Fe, Cr, V. Besides M_6C, the $M_{23}C_6$ and MC carbides can occur, but published data on these subsidiary carbides are conflicting, probably because they occur in much smaller quantities. In many cases the quantity is close to or below the limit of detection of the X-ray method used, or the carbides have been identified from two characteristic lines only. As the compositions of several high-speed steels are close to the $M_6C/(M_6C + M_{23}C_6)$ limit, variations in the amount of carbide-forming elements or heat-treatment may result in different carbide compositions. Only Kuo recognized the M_7C_3 carbide in high-speed steel.

The published data indicate that the M_6C and MC carbides dissolve partially at the usual austenitizing temperatures, while $M_{23}C_6$ dissolves completely at lower temperatures.[14, 17]

Opinions differ as to the mechanism of dissolution of M_6C. Gill, Gulayev, and Goldschmidt suppose this carbide to remain unchanged, while Arkharov *et al.* conclude from the increase of lattice parameters of M_6C extracted from hardened specimens that changes in composition do occur.

It was therefore considered of interest to obtain more data on carbides in high-speed steels. As the effect of austenitizing depends on temperature and time, the time factor needed to be studied too. For practical reasons only two grades of high-speed steel, 18–4–1 and 9–4–2, were chosen, these being the grades most widely used in Poland.

METHODS

Besides standard metallographic methods the carbide residue obtained by electrolytic extraction was found to be a suitable material for X-ray and chemical examination. Published data[13, 15, 16] and our preliminary studies have shown that 5% hydrochloric acid is the most suitable electrolyte for the extraction of carbides from high-speed steel.

The M_6C carbide, which has a high absorption power for X-rays and constitutes often at least 80% of the residue, tends to prevent the identification of minor carbides. By removing M_6C and identifying the remaining carbides, more accurate data can be obtained. A selective method of dissolution of carbides indicated by Popova *et al.*[18, 19] consists of treating the carbide residue with a hot solution of hydrochloric acid and hydrogen peroxide [50 ml H_2O_2 (30%) + 25 ml HCl (1·19)+100ml H_2O/g of residue]. Chromium-rich carbides are passivated whereas others dissolve.

The chemical composition of steels used is given in Table I. Specimens 10 mm dia. and 40 mm long were machined from soft-annealed bars. Heat-treatment consisted in preheating for 15 min at 800° C, austenitizing, and oil-quenching. Austenitizing temperatures for specimens of both steels were 900°, 1 000°, 1 100°, and 1 200° C. Furthermore specimens of 18–4–1 steel were austenitized at 1 250° and 1 300° C, and of 9–4–2 steel at 1 230° and 1 260° C. Soaking times at each temperature were 1, 5, 10, and 20 min.

RESULTS

Microscopical examination and hardness testing

Micrographs of annealed 18–4–1 and 9–4–2 steels (Figs. 1, 2) show spheroidized carbides in a ferrite matrix. Temperature and time of austenitizing affect the size and shape of undissolved carbides especially in 18–4–1 steel. Beginning at 1 250° C the growth of carbide particles having a polygonal structure may be observed. This clearly does not occur in 9–4–2 steel. The 9–4–2 steel shows a much greater tendency to austenite grain growth than 18–4–1. Rockwell C hardness tests were made on specimens which were

TABLE I Chemical analysis of steel specimens

Steel	Contents, % C	Mn	Si	P	S	Cr	W	V	Mo
18–4–1	0·77	0·42	0·21	0·027	0·020	4·60	18·79	1·55	0·26
9–4–2	0·81	0·13	0·14	0·013	0·014	4·54	8·52	2·20	0·16

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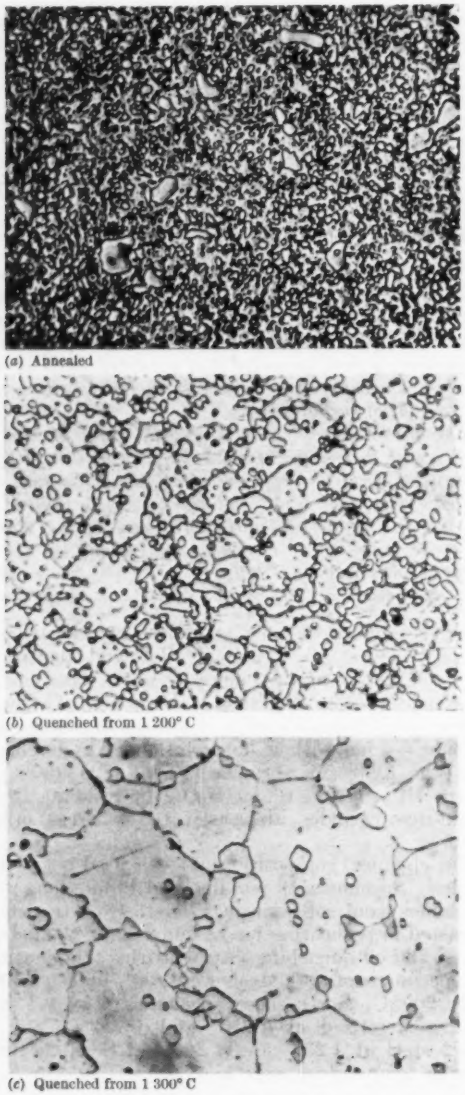
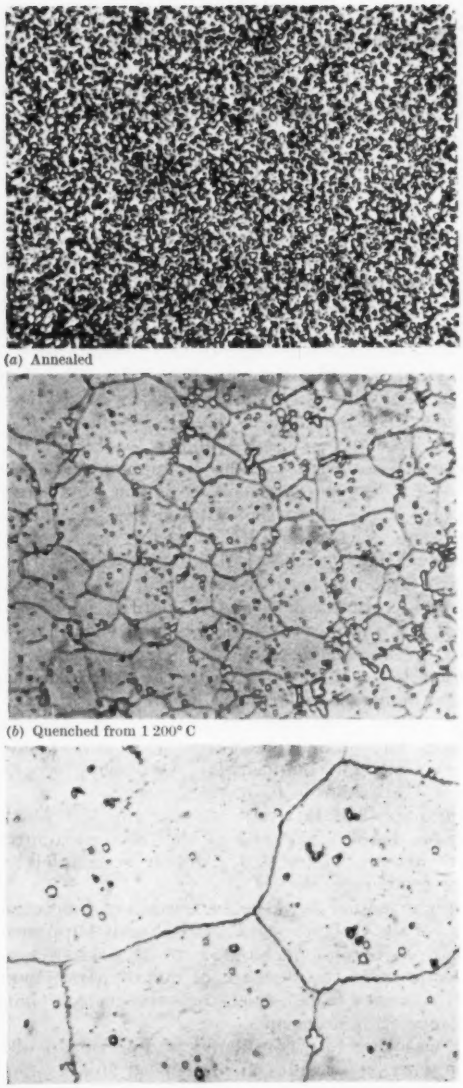


(*a*) Annealed

(*b*) Quenched from 1 200° C

(*c*) Quenched from 1 300° C

1 *Micrographs of polished specimens of 18–4–1 steel* ×800



(*a*) Annealed

(*b*) Quenched from 1 200° C

(*c*) Quenched from 1 260° C

2 *Micrographs of polished specimens of 9–4–2 steel* ×800

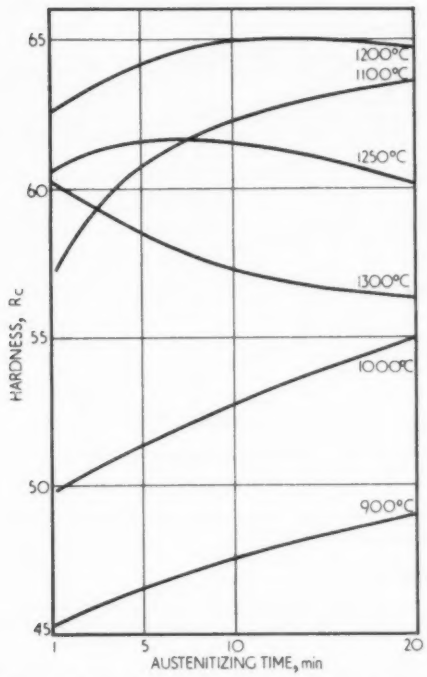
used for microscopic examination. Graphs of hardness/time and temperature of austenitizing are shown in Figs. 3 and 4.

Chemical composition of the residue

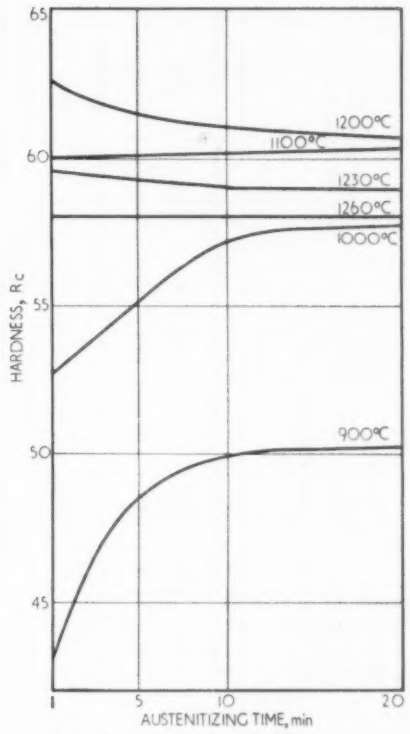
The carbides were extracted using a 5% hydrochloric acid solution and direct current. Samples austenitized at 900–1 200° C dissolved in 90 min using a current density of 0·03 A/cm². For samples austenitized at higher temperatures the carbides were extracted using a current density of 0·01 A/cm² over a period of 18 h. This was necessary because at 0·03 A/cm² the residue from samples quenched above 1 200° C was contaminated with matrix particles. With lower current densities this contamination is smaller but is, however, still present as can be shown by placing the residue in a magnetic field.

Table II shows the distribution of alloying elements between the carbides and the matrix in the annealed and quenched conditions. Data for quenched specimens are limited to 1 250° C for 18–4–1 and 1 230° C for 9–4–2. Figures 5–8 show graphs of amount of residue and alloying elements against time and temperature of austenitizing.

The residue contains free carbon as well as carbides. The main constituents are W, Cr, V, Fe, and C. The sum of these elements should therefore be in the region of 100%. Chemical analysis has shown that the sum varies around 95%. The deficiency can be attributed to the presence of small quantities of other carbide-forming elements, e.g. Mo and Mn, and also to inherent errors in extraction and analysis. In general, however, it seems that the accuracy is good enough to make a review of the effect of heat-treatment possible.



3 *Hardness of quenched 18–4–1 steel* v. *time and temperature of austenitizing*



4 *Hardness of quenched 9–4–2 steel* v. *time and temperature of austenitizing*

X-ray examinations

Phase identification on unprepared specimens which have not been changed by preliminary treatment would seem to be the most appropriate method to use but may not reveal minor phases.

This was the reason why identification was also carried out on residues from electrolytic extraction. Before identification of minor phases M_6C was dissolved and identification carried out on the residue.

X-ray patterns from polished specimens were obtained with a Bragg–Brentano camera of 114·6 mm dia., using Co K_α-radiation.

The patterns of annealed 18–4–1 show lines of α-phase and M_6C. There are also two weak lines which could not be identified.

The patterns of annealed 9–4–2 contain lines of α-phase, M_6C and MC carbides.

Quenched 18–4–1 and 9–4–2 specimens produce patterns containing lines of γ phase, after austenitizing at temperatures above 1 200° C. The higher the austenitizing temperature the greater is the intensity of these lines. The intensity of M_6C and MC lines diminishes with dissolution in the matrix. Lines corresponding to high Bragg angle are disappearing on patterns of specimens quenched from high temperatures.

The patterns of the residue were obtained using Cr $K_{\alpha\beta}$-radiation and a camera of 114·6 mm dia. The patterns of the residue from annealed 18–4–1 show M_6C to be the predominant constituent. There are also weak lines of the $M_{23}C_6$ carbide. The patterns of the residue from all 18–4–1 quenched specimens also show M_6C as the predominant constituent, with the exception of those austenitized for 1 min at 900° and 1 000° C. These exhibited two or three very weak lines which could be attributed to the $M_{23}C_6$ carbide. Clearly separated $\alpha_1\alpha_2$ doublets indicate that the structure of M_6C is undisturbed.

The M_6C is also the predominant constituent in annealed and quenched 9–4–2. In the patterns of all residues fairly strong lines of MC carbide were found. In the residues of 9–4–2 steel, annealed or quenched from 900° and 1 000° C (soaking time 1 min) there were some weak lines which could be attributed to the M_7C_3 carbide.

The separation of iron–tungsten carbide from the residue was carried out according to the method of Popova and Sorokina.[19] MC was found dissolved together with M_6C.

The selective dissolution of carbides was carried out on residues from annealed or quenched (from 1 100° and 1 200° C) steel, because annealed samples contained the greatest amount of chromium-rich carbides and at 1 100° and 1 200° C these carbides should completely dissolve.

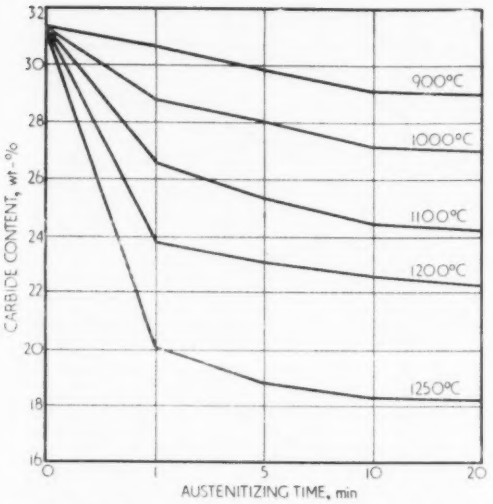
The patterns of residue from annealed 18–4–1 steel after removing the M_6C carbide reveal that the only carbide present is $M_{23}C_6$ (about 12%). The residue of annealed 9–4–2 steel after a similar treatment gives a pattern of M_7C_3 carbide (about 16%). Selective dissolution of the residue from samples quenched at 1 100° C has shown no $M_{23}C_6$ or M_7C_3 carbides.

Figures 9 and 10 show patterns of the residue from 18–4–1 and 9–4–2 steel before and after selective dissolution.

TABLE II Content of alloying elements in carbides and matrix of quenched and annealed 18–4–1 and 9–4–2 steels

	Alloying elements in steel, %	Annealed				Quenched				Phase composition (X-ray determination)
		Alloying elements in carbides, % (relating to steel)		Alloying elements in matrix, % (relating to steel)		Alloying elements in carbides, % (relating to steel)		Alloying elements in matrix, % (relating to steel)		
		18–4–1	9–4–2	18–4–1	9–4–2	1 250°C*	1 230°C*	1 250°C*	1 230°C*	
1	2	3		4		7		8		
	18–4–1	9–4–2	18–4–1	9–4–2	18–4–1	9–4–2	18–4–1	9–4–2	18–4–1	9–4–2	
W	18·74	8·52	17·83	7·40	1·08	1·05	57·5	45·6	11·82	1·88	6·95	6·70	ferrite + M_6C	ferrite + M_6C + $M_{23}C_6$ + M_7C_3
Cr	4·60	4·54	2·36	2·15	2·27	2·48	7·5	13·2	0·44	0·08	4·40	4·56	martensite + M_6C	martensite + M_6C + $M_{23}C_6$ + M_7C_3
V	1·55	2·20	1·26	1·76	0·27	0·31	4·0	10·9	0·41	0·48	1·10	1·70	austenite + M_6C	austenite + M_6C + $M_{23}C_6$ + M_7C_3
Fe	...	...	7·79	3·40	...	...	25·0	20·9	3·90	0·56	...	...	20·4	13·6	MC + M_6C	MC + M_6C + $M_{23}C_6$ + M_7C_3
													10			
													1 250°C*	1 230°C*	1 250°C*	1 230°C*
													18–4–1	9–4–2	18–4–1	9–4–2
													martensite + austenite + M_6C + $M_{23}C_6$ + M_7C_3	martensite + austenite + M_6C + $M_{23}C_6$ + M_7C_3	martensite + austenite + M_6C + MC	martensite + austenite + M_6C + MC

* Soaking time 20 min



5 *Wt-% of carbides in quenched 18–4–1 steel v. time and temperature of austenitizing*

DISCUSSION

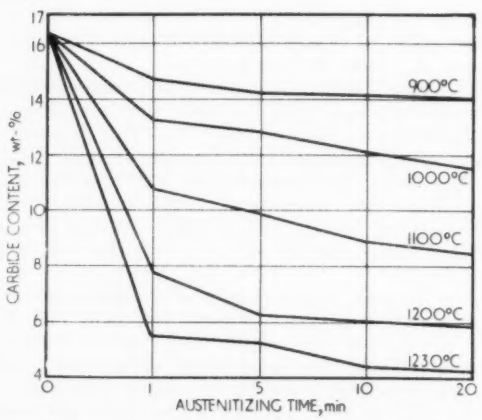
The change in hardness of 18–4–1 and 9–4–2 high-speed steels (Figs. 3 and 4) can be divided into three stages:

1. Hardness increases rapidly with temperature and soaking time, e.g. at 900°, 1 000°, and 1 100° C in 18–4–1 steel and at 900° and 1 000° C in 9–4–2 steel.

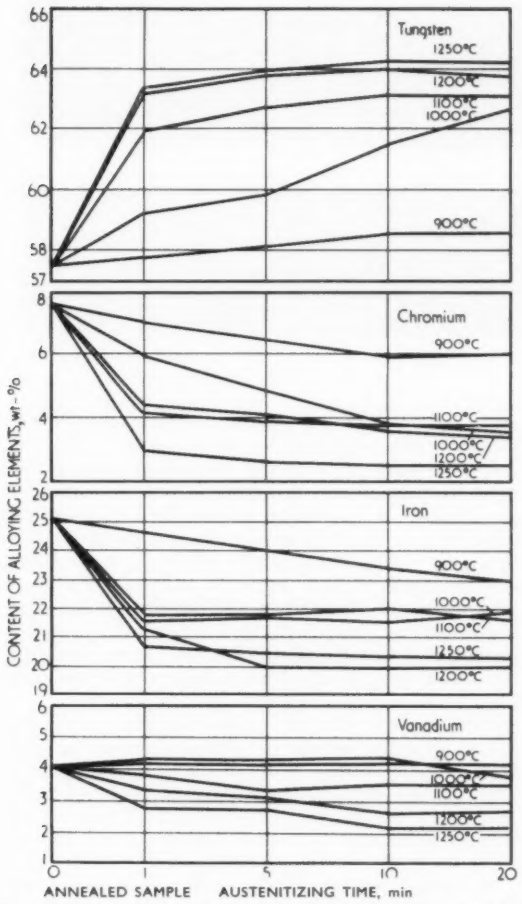
2. Increase of temperature causes a higher hardness, time of soaking does not influence the hardness, e.g. 1 200° C, 18–4–2 steel; 1 100° C, 9–4–2 steel.

3. Further increase of temperature and soaking time results in lower hardness, e.g. 1 250° and 1 300° C for 18–4–1 steel and 1 230° and 1 260° C for 9–4–2 steel.

A fact well known in practice is shown, i.e. that the higher the quenching temperature, the shorter the time required to achieve the maximum hardness. If the soaking time exceeds an optimum a decrease of hardness due to formation of retained austenite occurs in 18–4–1 steel at 1 300° C and in 9–4–2 steel at 1 200° C.



6 *Wt-% of carbides in quenched 9–4–2 steel v. time and temperature of austenitizing*



7 *Wt-% of alloying elements in the residue from quenched 18–4–1 steel* v. *time and temperature of austenitizing, annealed specimen*

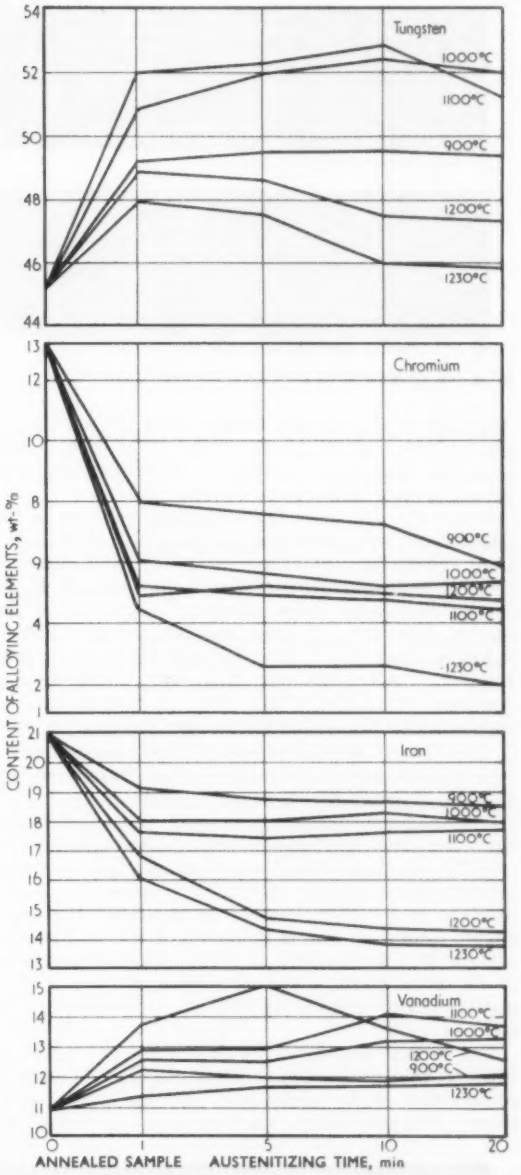
Table II and Figure 11 show that the content of alloying elements in the matrix is similar in both the annealed and the quenched condition, in spite of the great difference in tungsten content of the two steels. The same was found by Kayser and Cohen.[14]

Differences are principally in the amount and nature of carbides: the 18–4–1 steel quenched from 1 250° C contains about 20 wt-% carbides but the 9–4–2 quenched from 1230°C only about 4 wt-%. In the first about 36%, in the second about 75% of the carbides present in the annealed state are dissolved. It follows from this that the matrix of 9–4–2 steel contains more carbon than that of 18–4–1, although there are significant differences in the carbon contents of particular carbides in both steels. This accounts for the different properties of the steels.

M_6C does not have the same composition in both steels, this can be deduced from differences in lattice parameters of carbides separated from annealed specimens. They are:

$$a_0 = 11{\cdot}0266 \text{ kX for } 18\text{–}4\text{–}1 \text{ steel}$$
$$a_0 = 11{\cdot}0197 \text{ kX for } 9\text{–}4\text{–}2 \text{ steel.}$$

According to Arkharov[17] it seems that the M_6C carbide from 18–4–1 steel contains more tungsten.

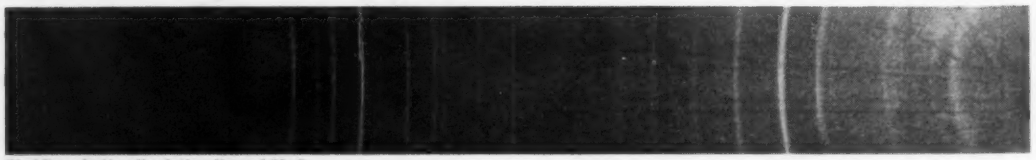


8 *Wt-% of alloying elements in the residue from quenched 9–4–2 steel* v. *time and temperature of austenitizing annealed specimen*

Carbides occurring in quenched steels show the presence of stresses indicated by diffused X-ray reflections at high Bragg angles. These stresses disappear in carbides extracted from steel, which have well defined back-diffraction lines with separate α_1 and α_2 doublet. The influence of the surrounding matrix seems to be the cause of stresses in carbides.

In 18–4–1 steel no MC carbide rich in V was found. If the total amount of V (4%) existing in the residue from annealed steel was combined in the form of MC this carbide should be identifiable by X-ray powder analysis if the detection limit is 2%. Since identification was negative, it seems that V is a constituent of

(*a*) Before selective dissolution, lines of M_6C



(*b*) After selective dissolution, lines of $M_{23}C_6$

9 *X-ray patterns of residues from annealed 18–4–2 steel*

M_6C and $M_{23}C_6$. As the content of $M_{23}C_6$ is 12 wt-% the residue contains about 88 wt-% of M_6C. Consequently the total amount of M_6C (27·8%) and $M_{23}C_6$ (3·5%) in steel can be calculated.

From the curves of the chromium content of the residue plotted against austenitizing temperature and time, which are identical at 1 100° and 1 200° C (Fig. 7), from Fig. 11, and from the absence of $M_{23}C_6$ in the remainder after selective dissolution of the residue from the specimen austenitized at 1 100° C, it follows that $M_{23}C_6$ is completely dissolved at 900–1 100° C. After dissolution of $M_{23}C_6$ the residue contains still about 5%Cr (Fig. 7) indicating that chromium is also combined in the M_6C carbide.

The Fe content of the residue drops simultaneously with the decrease in Cr content. It follows from this that $M_{23}C_6$ contains Fe as well as Cr.

The tungsten content of the residue increases within the austenitizing temperature range 900–1200° C (Fig. 7) because of dissolution of $M_{23}C_6$ in the austenite. From 1 200–1 250° C there may also be an increase in tungsten content of the residue, though slight, caused by the enrichment of the undissolved carbide M_6C by tungsten, and simultaneous migration of Fe or Cr atoms. This is confirmed by a further decrease in Fe and Cr contents of specimens austenitized at 1 250° C.

The intense dissolution of M_6C begins at 1 200° C. It seems that at this temperature changes in chemical composition of the undissolved particles start to take place. The possibility of such changes, indicated by Arkharov *et al.*, was not confirmed by Goldschmidt.[9,10]* This problem needs further investigation.

The amount of V in the matrix of 18–4–1 steel increases perceptibly at 1 200° C. The V content of the residue of specimens austenitized at 900° and 1 000° C (*see* Fig. 7) increases slightly due to a drop of $M_{23}C_6$. At 1 200° C and 1 250° C there is a pronounced decrease in V content.

In 9–4–2 annealed steel the carbides M_6C, M_7C_3, and MC are present. As in 18–4–1 steel, the identification of the Cr-rich M_7C_3 due to separation from M_6C and MC, is unquestionable and agrees with Kuo.[12]

The tungsten content of 9–4–2 steel equals half that in 18–4–1 with almost equal C contents. Thus the Cr, having more C at its disposal, forms a carbide richer in C. M_7C_3 in the residue of annealed 9–4–2 steel is 15 wt-%, thus the total of M_6C and MC carbides is 85 wt-%, i.e. 13·6% of M_6C and MC and 2·6% of M_7C_3.

M_7C_3 dissolves completely in the matrix at between 900° and 1 100° C (Fig. 8) similar to $M_{23}C_6$ in 18–4–1 steel. The residue contains about 5%Cr, probably combined as the M_6C carbide.

The decrease of Fe content in the residue (Fig. 8)

* It is possible that the variations in composition of carbides are connected with known phenomenon which consists in the adoption of polygonal shapes during austenitizing at high temperatures. This supposition is contradicted by the work of Hergue *et al.*[21] who maintain that both globular and polygonal carbides have the same structure and composition.

(*a*) Before selective dissolution, lines of M_6C and MC

(*b*) After selective dissolution, lines of M_7C_3

10 *X-ray patterns of residues from annealed 9–4–2 steel*

is caused by the dissolution of M_7C_3 carbide containing Fe.

The tungsten content in the residue increases in the range 900–1 100° C, and then decreases rapidly (Fig. 8). The decreasing amount of M_7C_3 at 900–1 100° C accounts for the increase of W in the residue. At 1 200° C and 1 230° C however the W content decreases due to intensive dissolution of M_6C and to the higher free C content.

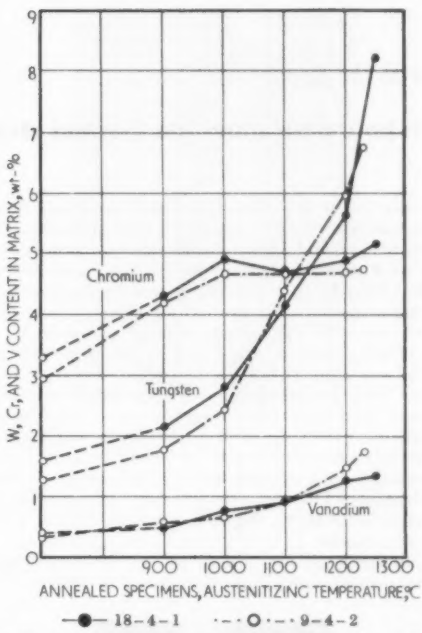
The same reasons apply to the decrease in Fe and Cr contents in the residues from specimens quenched from 1 200° and 1 230° C.

The V content in the residue increases with temperature up to 1 200° C, owing to the dissolution of M_7C_3 in austenite. Since the intensive dissolution of V begins at about 1 200° C, this accounts for a drop in V in the residue above 1 200° C.

These results relating to the composition of the residue agree with Papier.[15] No great decrease of W, Cr, and Fe content, as stated by Papier, was observed at temperatures 1 150–1 200° C.

Electrolytic extraction was found to be more difficult at higher austenitizing temperatures. According to Papier,[15] Gulayev,[16] Blickwede and Cohen[13] the residue become contaminated with matrix, and the results of chemical analysis are not precise. The present authors have found that if the austenitizing temperatures exceeded 1 200° C the residue is slightly magnetic, this can be only explained by the presence of undissolved matrix, which was also identified by X-rays. If lower current densities are used, the degree of contamination is lower, but attempts to establish even a rough correlation of the electrolysis parameters (current density, electrolyte temperature, anode potential, and time) and the degree of contamination failed. Therefore it seems that the contamination is not due to the mechanism of electrolysis but depends rather on the structure of samples.

According to Papier[15] the residue from the surface layer of the specimen is more contaminated than that from the core owing to stresses present in the surface layer. In the present work the specimen was etched therefore 1–2 mm away but the residue was still magnetic. Only after prolonged extraction with 5% HCl were the particles of matrix dissolved. Prolonged treatment with HCl may, however, attack finely dispersed carbides.



11 *Wt-% of alloying elements in the matrix of annealed and quenched 18–4–1 and 9–4–2 steels* v. *austenitizing temperature (soaking time 20 min)*

CONCLUSIONS

1. The matrix of annealed and quenched 18–4–1 and 9–4–2 steels contain almost the same amounts of alloying elements. The differences between these steels consist principally in the amount and composition of carbides.

2. The following carbides were found:
   18–4–1 steel:
   annealed, M_6C and $M_{23}C_6$
   quenched 1 300° C, M_6C
   9–4–2 steel:
   annealed, M_6C, M_7C_3, MC
   quenched 1 260 C°, M_6C, MC

3. The amount of carbides differ depending on the type of steel and its heat-treatment:
   18–4–1 steel:
   annealed, 31·2 wt-%
   quenched 1 250° C, about 20 wt-%
   9–4–2 steel:
   annealed, 16·2 wt-%
   quenched 1 230° C, about 4 wt-%

4. The predominant carbide in both grades of steel is M_6C. Its composition differs depending on the grade of steel. In 18–4–1 the M_6C carbide is richer in tungsten.

5. During austenitizing $M_{23}C_6$ and M_7C_3 dissolve first. The dissolution is completed at about 1 100° C.

6. Intensive solution of tungsten and vanadium in the matrix begins at 1 200° C.

REFERENCES

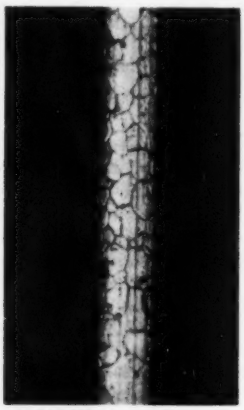
1. A. Westgren: *Jernkont. Ann.*, 1933, **88,** 501–512.
2. A. Westgren and G. Phragmen: *Zeitschrift für anorganische und Allgemeine Chemie*, 1927, **110,** 535.
3. A. Westgren: *Jernkont. Ann.*, 1933, **88,** 1–14.
4. Ya. Umansky and M. Chebotarev: *Izvest. Akad. Nauk USSR., Seriya Fiz.*, 1951, **15,** 24.
5. M. Chebotarev: *ibid.*, 1951, **15,** 39.
6. H. Krainer: *Archiv Eisenhüt.*, 1950, **21,** 33–38.
7. H. J. Goldschmidt: *JISI*, 1948, **160,** 345–362.
8. H. J. Goldschmidt: *Metallurgia*, 1949, **40,** 103–104.
9. H. J. Goldschmidt: *JISI*, 1952, **170,** 189–204.
10. H. J. Goldschmidt: *ibid.*, 1957, **186,** 68–85.
11. K. Kuo: *ibid.*, 1953, **173,** 363–375.
12. K. Kuo: *ibid.*, 1953, **174,** 223–228.
13. D. J. Blickwede and M. Cohen: *Trans. AIME*, 1949, **185,** 578–584.
14. F. Kayser and M. Cohen: *Met. Prog.*, 1952, **61,** (6), 79–85.
15. J. Papier: *Rev. Mét.*, 1954, **51,** 723.
16. A. Gulayev: *Stal'*, 1946, (3), 188.
17. W. Arkharov, I. Kvater, and S. Kiselev: *Izvest. Akad. Nauk USSR., Seriya Fiz.*, 1947, **11,** 749–756.
18. M. Popova and K. Sorokina: *Zavods. Lab.*, 1953, **19,** 1033.
19. M. Popova and K. Sorokina: *ibid.*, 1955, **21,** 527–530.
20. J. P. Gill: *Trans. ASM*, 1935, **24,** 735–782.
21. C. J. McHargue, J. P. Hammond, and C. Crouse: *Trans. ASM*, 1954, **46,** 716–752.

Letter to the Editor

Grain boundaries and the thermal etching of iron

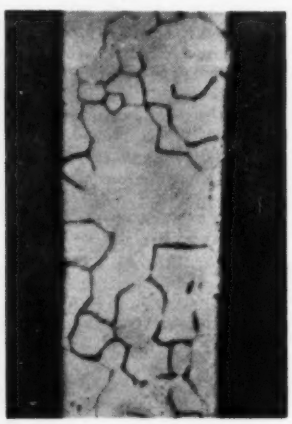
AS A PRELIMINARY to work on the surface energy of solid iron, it became necessary to investigate the thermal etching characteristics of the metal. Iron from two different sources was used in the work. BISRA kindly presented sheet and 40 swg wire samples of Swedish iron purified by melting successively in an oxidizing atmosphere, in dry hydrogen, and finally *in vacuo* (BISRA iron AH). The purity was estimated to be better than 99·96%, the nitrogen content being 0·0019%. This material was supplied in the cold-worked condition. Johnson, Matthey Ltd provided 40 swg wire in the cold-drawn condition (JM iron). Hydrogen-reduced sponge was sintered in cracked ammonia at 1 180°C to form a rod, which was then drawn through dies with intermediate annealing at 850°C in cracked ammonia. Spectrographic analysis by the makers indicated a metallic purity of 99·98%. The nitrogen content of the wire as received was 0·0132%, but after thermal etching it was as shown in the table.

In all the work now described, no difference could be detected between specimens from these very different sources.



←— wire dia. —→

1 *Surface of JM wire after heating to 850°C* × 250



2 *Section of JM wire after heating to 850°C; nital etch* × 250

Thermal etching was carried out at three temperatures, as shown in the table.

Temp., °C	Atmosphere	Illustrations	Final nitrogen content JM wire
850	Vacuum	Fig.1	0·0097%
1 400	Purified argon	Fig.3	
1 480	Purified argon	Figs.4 and 5	0·0035%

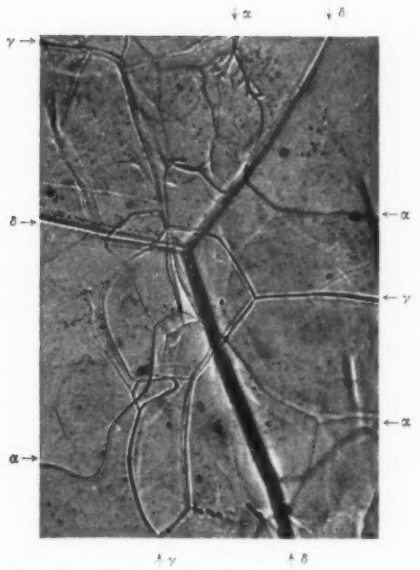
Figure 3 clearly shows the thermal etching grooves which formed on the sites of γ-grain boundaries, and the grooves at the α-grain boundaries. Figures 4 and 5 are more difficult to interpret. There are clearly three independent sets of grooves showing in Fig.5 and an interpretation is suggested. Wires under a small axial stress ($2{\cdot}0 \times 10^4$ dyn/cm²) frequently showed offsetting in a direction which decreased the length of

←— wire dia. —→

3 *Surface of AH wire after heating to 1 400°C* × 250

←— wire dia. —→

4 *Surface of AH wire after heating to 1 480°C* × 250

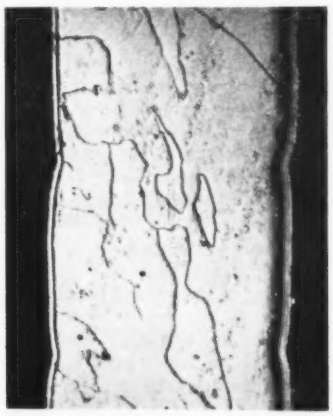


5 *AH iron sheet after heating to 1 480°C* ×400

the wire (Fig.7). The planes on which offsetting occurred always corresponded to scars of the grain-boundary grooves of the phase stable at the highest temperature.

After thermal etching at 1 400°C and 1 480°C some wires were nickel plated to preserve surface features, sectioned, polished with 1μ diamond paste, and etched with 2% nital. No structure at all was revealed over nearly all the area of the sections. In one small area only were a few lines seen after etching (Fig.6) and the pattern in this area was reproduced every time the specimen was polished and re-etched. These apparent α-grain boundaries bear little relationship to the grooves produced in the wire surface by the thermal etching of δ-iron. Sections of a wire which had been thermally etched at 850°C etched in the usual way, as shown in Fig.2, the only unusual feature being a small number of grain boundaries which apparently end in the middle of the grain. Transmission Laue X-ray photographs taken of bundles of wires indicated that the α-grain size of all specimens after thermal etching was of the same order.

It is possible to explain this effect as follows. The grain boundaries of nuclei of α-crystals growing in a cold-worked matrix are able to collect impurities from the metal. These



6 *AH iron wire heated to 1 480°C, plated, sectioned, etched in 2% nital* ×350

7 *Offsetting in iron wire after heating to 1 480°C* ×100

impurities reduce the grain-boundary energy, and so move with the boundaries. Thus in the specimens thermally etched at 850°C, there is a concentration of impurities at the grain boundaries. It is this concentration which is responsible for the etching of the boundaries by 2% nital, rather than the energy associated with the grain-boundary structure.

A grain boundary between the nucleus of a new phase and the matrix of the old phase during an allotropic transformation in a pure metal would probably not be able to carry impurities with it. There is usually a special relationship between the orientation of the grain of the new phase and that of the old phase in which it is growing, so that the boundary moves more rapidly and has a much lower energy as compared with the boundary separating cold-worked material and a recrystallization nucleus.

However, it is clear that since the γ-grain size in the specimens heated at 1 400°C is larger than the α-grain size in similar specimens heated at 850°C, grain growth must occur in the γ-phase. Similarly, it is clear from Figs.5 and 6 that when the specimen is slowly cooled, the grain boundaries in the old phase are not always grain boundaries in the new phase. Again, grain-boundary migration must occur after the formation of each new phase. Yet it seems that no significant migration of impurities occurs during this boundary migration, as none of the final α-grain boundaries are etched in most of the specimens. It seems necessary to postulate that the impurities migrate readily with grain boundaries when the latter are growing into a cold-worked α-matrix, but not otherwise.

Coulomb and Lacombe,[2] working with iron between 99·96 and 99·99% purity found that impurities segregate to grain boundaries when the metal was annealed in the α- or γ-phase. When boundaries migrate or are swept out by a phase transformation, the impurities remain as a network on the site of the former boundaries, and this network may be revealed by suitable etching reagents. Very long annealing times are required to break up this network and establish a new network on the new grain boundaries.

Internal friction measurements should provide a useful tool for the detailed examination of the grain boundaries after various thermal treatments. It is possible, too, that magnetic properties might be considerably influenced by these differences between the grain-boundary structures.

ACKNOWLEDGMENT

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REFERENCES

1. A. P. Greenough: *Phil. Mag.*, 1952, **63**, 1075–1082.
2. P. Coulomb and P. Lacombe: *Rev. Mét.*, 1958, **55**, 918–926.

Scale on mild steel in various stages of rolling wire rod

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SYNOPSIS

Samples were taken at various stages during the rolling of two mild-steel billets and the scale on the surface was subjected to exhaustive examination; the quantity of scale present and its adhesion during plastic deformation of the metal was estimated and the structure of the scale was investigated by X-ray and metallographic techniques. Mill variables, particularly cooling rate, have a profound influence on the thickness and structure of the scale, particularly on the extent of decomposition of wüstite below 570° C. All the samples showed evidence of separation of oxide from the substrate in the course of oxidation.

1598

THE KINETICS OF OXIDATION of pure iron and mild steel and the structure of the scale formed are fairly well understood as a result of the considerable amount of experimental evidence accumulated over the years. Most of this experimental work was done with clean specimens heated at controlled temperatures in controlled atmospheres and cooled under controlled conditions. In this way the nature of the three-layer scale was elucidated,[1] the effect of temperature and atmosphere on the distribution of the three oxide phases was established,[2, 3] the relation between the Fe–O equilibrium diagram and the structure of the scale was studied,[4, 5, 6] the kinetics of decomposition of wüstite below 570° C were investigated,[4, 8] and the question of porosity and separation of scale from the substrate was examined in some detail.[9, 10, 11]

The conditions under which commercial steels are heated in the works are more complicated and less controlled than those used in oxidation experiments. The surface generally carries the relics of all previous treatments, either scale or the cast skin formed on solidification in the mould. The steel is usually heated in the products of combustion of whatever gas is most economically available in the steelworks and the atmosphere is often contaminated with sulphur, which is known to affect scaling.[12] Temperature control, even where it is not neglected, allows much wider fluctuations than are permitted in the laboratory. In many operations the scale is knocked off the surface of the steel as soon as it is formed and fresh oxide grows on cooling under very ill-defined conditions; some attempts have been made to estimate rates of oxidation during continuous cooling by manipulating the equations for isothermal oxidation at different temperatures,[13] but the necessary simplifying assumptions are rather remote from steelworks practice.

The scale actually formed on commercial steels is worth studying for practical reasons. Apart from the fact that every ton of scale formed represents a loss of steel, there is considerable interest in scale from the viewpoint of surface defects: some defects are probably scaled away in reheating furnaces, others may be introduced when adherent scale is rolled into the surface. Ultimately the scale has to be removed, and both pickling and mechanical descaling are influenced by the type of scale present on the surface. For these reasons detailed examinations of the scale formed on steels in the course of steelworks processing have been in progress in various centres for some time. The most important of these are probably Moreau's studies at IRSID, of the scale on ingots after stripping from the mould and after discharge from the soaking pit[14] and of the scale on billets of mild and medium-carbon steels reheated in various works.[15] At the Max-Planck Institute the scale on hot-rolled plate and strip and

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the effect of steelmaking variables and cooling rates on the scale structure have been studied with special attention to the ease of pickling[16] and the mechanical adhesion of the scale to the surface.[17] A study of the scale on wire rod rolled in different steelworks is in progress at BISRA.[18]

The main interest in the present work was the structure of the scale on wire rod and its ease of removal by plastic deformation of the rod. Some attention was paid to the scale on the billet before and after reheating and to the possibility that billet scale rolled into the surface might be present on the wire rod. Since it was desired to compare the scale on a billet with that on rod rolled from the same billet, samples were taken during the rolling operation in a Morgan mill. It was found possible and convenient to cut off samples at a number of stages during the rolling process, e.g. at flying shears in the train, or at points in the operation where the stock was stationary for long enough to allow a short piece to be cut off. Rolling in this type of mill is extremely rapid so that the drop in temperature is slight and the temperature at any stage in the mill operation is reasonably well known. Differences in cross-section led to considerable differences in cooling rate and the influence of this factor could be detected in the scale with some sensitivity.

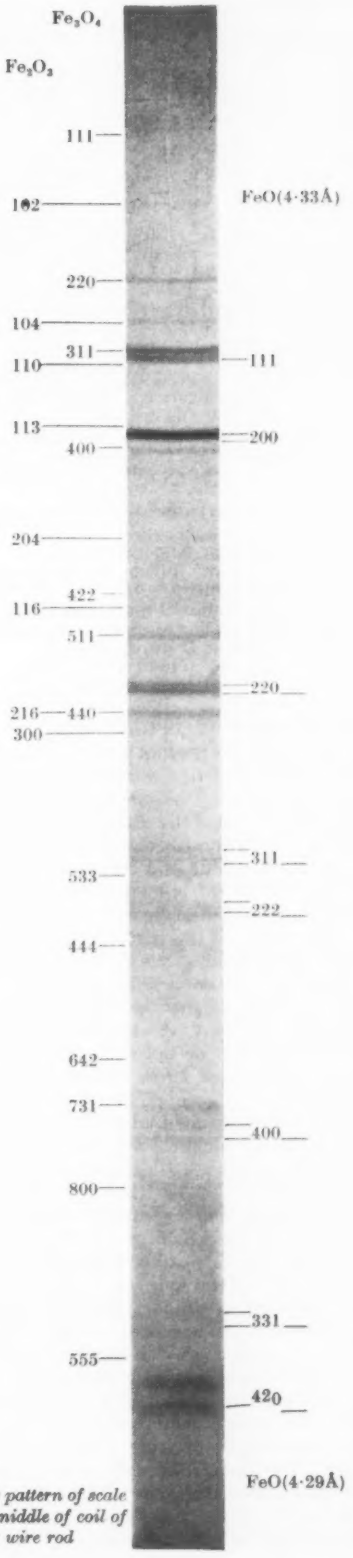
MATERIAL AND SAMPLES

Two hot-rolled billets of rimming steel, $2\frac{1}{4}$ in. square, were taken from the billet stock at the rod mill. Details of the analysis (percent) were as follows:

		C	Si	Mn	S	P
Billet A	Edge	0·04	0·02	0·31	0·03	0·015
	Core	0·08	0·01	0·34	0·07	0·024
Billet B	Edge	0·08	0·01	0·35	0·05	0·018
	Core	0·18	0·015	0·40	0·12	0·030

The billets came from different casts; billet *B* came from the top of the ingot, billet *A* from the main part. In spite of the difference in composition and in degree of segregation, no significant differences between the two billets were found in the scale formed at various stages of rolling and illustrative examples have been chosen from different billets.

The billets were rolled to 5 swg wire rod in a Morgan continuous rolling mill. The billets are heated to about 1200–1120°C in a furnace fired with enriched blast-furnace gas. The atmosphere is likely to contain some sulphur; it may accelerate oxidation above the rate corresponding to purer atmospheres but detailed examination of the scale on the billet revealed no features directly attributable to sulphur. The billets are in the furnace for about 2 h altogether and are at temperature for about 15–20 min. They enter the roughing train fairly slowly, so that a piece can be cut off the back end. The roughing train consists of 10 stands; at stand 10 the material emerges as $\frac{5}{8}$-in. rod and there is a flying shear at this point. The $\frac{5}{8}$-in. rods then pass through the finishing train of 5 stands emerging as 5 swg rods at temperatures of the order of 950–1000°C. The rods are cooled to 850° C by water circulating in the guide tubes and reeled into 480-lb coils. The whole operation, including reeling, takes about 2 min. The coils are conveyed to a transfer point where they are picked up by hooks suspended from an overhead chain; they cool freely in air for about $\frac{1}{2}$ h before they are unloaded and stacked.



1 *X-ray pattern of scale from middle of coil of 5 swg wire rod*

TABLE I Phases present in scales

	Hot rolled	Re-heated	⅝-in. rod at stand 10	5 swg wire rod last wrap at reels	5 swg wire rod front of cold coil	5 swg wire rod middle of cold coil	5 swg wire rod back of cold coil
Billet A							
Mechanically stripped	FeO (4·33) Fe_3O_4	Fe_3O_4 FeO (4·33 and 4·29 equal)	FeO (4·29) Fe_3O_4	FeO (4·29) Fe_3O_4	FeO (4·29) Fe_3O_4 FeO (4·33) tr	FeO (4·29) FeO (4·33) Fe_3O_4	FeO (4·29) Fe_3O_4 FeO (4·33)
Iodine stripped	FeO (4·33) Fe_3O_4 FeO (4·29) (all lines very diffuse)	FeO (4·29) Fe_3O_4 tr Fe tr	FeO (4·29) Fe_3O_4	FeO (4·29) Fe_3O_4	FeO (4·29) Fe_3O_4	FeO (4·29) Fe_3O_4 FeO (4·33)	FeO (4·29) Fe_3O_4 FeO (4·33)
Billet B							
Mechanically stripped	Fe_3O_4 FeO (4·33) Fe_2O_3	FeO (4·29) Fe_3O_4	FeO (4·29) Fe_3O_4 FeO (4·33) tr?	FeO (4·29) Fe_3O_4	Feo (4·29) Fe_3O_4 FeO (4·33)	FeO (4·29) Fe_3O_4 FeO (4·33)	FeO (4·29) Fe_3O_4 FeO (4·33) tr
Iodine stripped	Fe_3O_4 FeO (4·33) FeO (4·29) tr? (all lines diffuse)	FeO (4·29)	FeO (4·29) Fe_3O_4 Fe_2O_3 tr	FeO (4·29) Fe_3O_4	FeO (4·29) Fe_3O_4 FeO (4·33)	FeO (4·29) Fe_3O_4 FeO (4·33)	FeO (4·29) Fe_3O_4 FeO (4·33) tr

Note: In X-ray analyses, oxides are placed in order of decreasing line intensity on the X-ray pattern

Samples were taken from each billet at the following stages:

(i) Hot-rolled 2¼-in. billet
(ii) Reheated 2¼-in. billet (from furnace before roughing train)
(iii) ⅝-in. rod at stand 10 (end of roughing train)
(iv) 5 swg rod at reeling stage (end of finishing train)
(v) ,, ,, ,, from front of cold coil
(vi) ,, ,, ,, ,, middle of cold coil
(vii) ,, ,, ,, ,, back of cold coil.

METHODS OF EXAMINATION

The quantity of scale present and the fraction which came off during cold deformation of the steel were estimated by weighing before and after mechanical and chemical removal of the scale. Mechanical removal involved 10% plastic stretching of short lengths of rod in a tensile machine and chipping the outer scale layer off the surface of billet samples. The methods of chemical removal of scale were improved progressively in the course of the investigation so that later results are more reliable than earlier ones; unfortunately there was not enough material left at the end to repeat the early weight-loss determinations by the method finally selected. This aspect of the experimental technique will be borne in mind in discussing the results. Altogether, three chemical methods were tried; ammonium citrate pickling, iodine stripping, and electrolytic sodium hydroxide pickling. The ammonium citrate pickling method[19] was originally believed to cause only a little attack on the underlying metal; experience showed that all the scale was removed but there was a definite metal loss so that the figures for the weight of scale removed were too high. Attempts were made to determine the quantity of scale removed by the iodine stripping method; the Formvar film used to support the scale during stripping was dissolved in hot 50% acetic acid, and the scale which remained was weighed. Unfortunately there was also some dissolution of the scale and some handling loss due to the fineness of the particles of scale after the acetic acid treatment, so that the figures for the weight of scale stripped off were too low. Finally, the amount of scale removed chemically has been determined from the weight loss in electrolytic pickling in a molten sodium hydroxide bath using an iron pot as one electrode and the specimen as the other. Full mains voltage and a current of 4 A were used, and the time of pickling was 80 min; loss of metal from unoxidized steel surfaces was negligible. Evidently, electrolytic treatment in molten caustic soda yielded the most reliable figures.

For X-ray examination of the separate scale fractions, duplicate specimens were stretched in the tensile machine and the scale which flaked off was collected. The adherent scale was removed from the surface by an alcoholic iodine stripping method,[20, 21] in which a Formvar film is deposited on the surface of the specimen; the oxides which are not dissolved in iodine adhere to this film and can be conveniently collected. After stripping, the Formvar film was dissolved in hot 50% acetic acid; the oxides were collected by centrifuging, dried, and then X-rayed. In the later stages of the work this technique was improved[22] by the use of a polyvinyl chloride–polyvinyl acetate resin (Rhodopas AXCM) in place of Formvar as the plastic support for the scale; this film could be redissolved in acetone which reduced the risk of preferential solution of any of the oxides present. The X-ray patterns produced by oxides collected in this way are much better than those obtained when the plastic film is present.

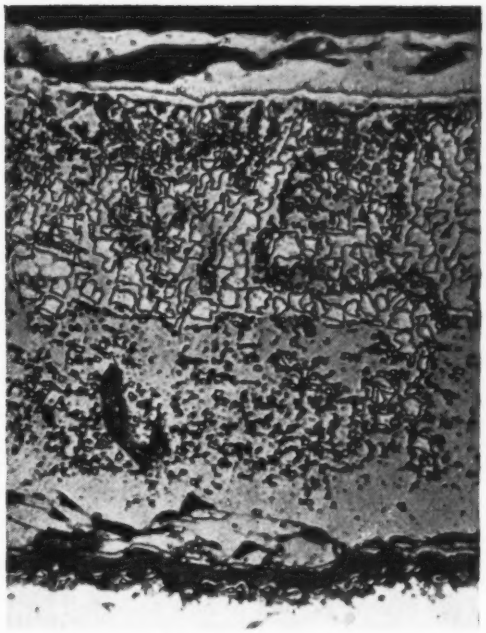
For metallographic examination the rod was not deformed and the scale was preserved and protected as far as possible. Short lengths of rod were mounted in Formvar,[23] and later in a cold-setting plastic[18]; they were then sectioned with a fine saw and mounted for polishing. Conventional diamond-powder polishing was quite satisfactory and the specimens were etched for 45 s in 0·5%HCl in alcohol or for about 5 s in 2% nital.

RESULTS OF EXAMINATION

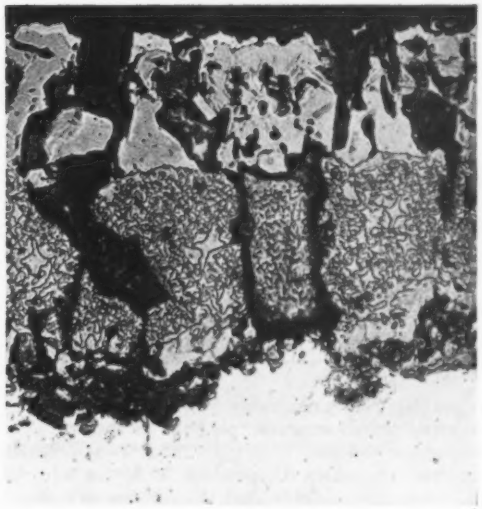
Decomposition of wüstite

The X-ray films were compared with standard patterns of the various oxides. The phases detected in the various samples are listed in Table I in order of predominance, estimated qualitatively on the basis of line intensity.

On most of the films the wüstite lines appeared in the form of doublets. Splitting of the lines of the wüstite pattern has been observed by Willis and



2 *Billet A, hot rolled* ×500



3 *Billet B, hot rolled* ×500

Rooksby[25] on prepared oxide samples cooled to 90° K. It was due to rhombohedral distortion of the wüstite lattice which produced certain characteristic effects: (*a*) the separation of the doublets is very different for different planes and the 400 line shows no splitting at all, and (*b*) the intensity differences are not uniform in all doublets, e.g. when the line intensities in the 220 doublet are equal, then in the 311, 222, 331, and 420 doublets the higher-angle lines are more intense than the low-angle ones.

Quite different patterns were obtained in the present work on scales at room temperature. A representative X-ray film is shown in Figure 1. Magnetite was present in the scale; the lines have been indexed on the film to avoid confusion with wüstite doublets. As far as the wüstite pattern itself is concerned, it will be noted (*a*) that the 400 line shows pronounced splitting and the separation of the doublets varies with the Bragg angle, and (*b*) that the line intensities are equal in all the doublets. On other films, the intensity ratios between high-angle and low-angle lines of different doublets are equal even if the intensities themselves differ.

It is clear from this comparison that the line splitting observed in the present work is not due to distortion of the wüstite lattice. The observations of doublet separation and line intensities suggest the presence of two self-consistent wüstite patterns, with lattice parameters of 4·33 Å and 4·29 Å respectively; they are recorded separately in Table I. The two parameters found correspond to the limits of the wüstite field, i.e. to saturation with oxygen and with iron respectively.

Wüstite is unstable below 570° C; the actual phases formed by its decomposition depend on the cooling rate. Under equilibrium conditions both iron and magnetite will precipitate from wüstite by a eutectoid reaction at 570° C. In practice, cooling rates are much faster and the eutectoid reaction is suppressed but other transformations take place. These transformations have been studied by isothermal methods,[7, 8, 28] at temperatures below 570° C, on bulk wüstite formed above 570° C. It has been shown that above 480° C iron is precipitated first, enriching the wüstite in oxygen until it has a lattice parameter of 4·29 Å. Below 480° C, magnetite is precipitated first, and the wüstite lattice is expanded by enrichment in iron and other impurities such as manganese. At much later stages in the decomposition below 480° C some iron is also precipitated. The decomposition of bulk wüstite proceeds at a maximum rate at temperatures of the order of 480° C,[7, 8, 28] when iron and magnetite are formed simultaneously.

In the present work, wüstite of two different compositions has been found in scales grown on steel products of various sections. Table I shows that FeO (4·33) predominates in billets, FeO (4·29) on rods. Some differences exist between rod samples: specimens cut off during rolling, e.g. at stand 10 and at the reels, have least FeO (4·33), in many cases none at all, while specimens cut from the middle of the cold coil, where the cooling rate has been slowest, have more FeO (4·33). Evidently FeO (4·33) forms during cooling and the longer the specimen is held in the temperature range where the reaction proceeds, the more FeO (4·33) is formed. It has been indicated that when a supercooled wüstite transforms isothermally, there is no splitting into wüstite of two parameters and the effect of prolonged treatment is that the parameter of all the wüstite present approaches more closely to that of the terminal solution. This difference may be due to slower progress of isothermal transformation allowing the wüstite to reach equilibrium. In the isothermal experiments, it took 2 h at 250° C and somewhat less than 20 h at 450° C for a modification in parameter to be detected. The coils of rod cool from 850° C to just above room temperature in ½ h so that they are in the temperature range below 480° C for about 20 min.

TABLE II Amount of scale on billets

	Weight of scale removed by chipping, g/m² of surface	Weight of scale removed chemically g/m² of surface		Total weight of scale g/m² of surface	Approx. mean
		Ammonium citrate	Iodine stripping		
Billet A					
Before reheating	332·5	332·5	...	665·0	660
	611·0	...	43·0	654·0	
After reheating	249·0	416·0	...	665·0	420
	149·6	...	27·4	177·0	
Billet B					
Before reheating	400·0	433·0	...	833·0	640
	395·0	...	50·0	445·0	
After reheating	222·4	285·6	...	508·0	525
	502·0	...	43·0	545·0	

It is not clear why continuous cooling should lead to more rapid transformation; perhaps as the specimens pass through the 480° C range a little transformation occurs and nucleates dissociation at lower temperatures. It is also possible that the difference is due to the composition of the original wüstite; isothermal studies have shown that wüstite with high oxygen contents decomposes more rapidly than wüstite saturated with iron.[8, 28]

The results in Table I indicate that slow cooling favours FeO (4·33), rapid cooling FeO (4·29). The most likely interpretation is that FeO (4·29) is the predominant phase at the temperature of scale formation and that local precipitation of magnetite causes enrichment of the wüstite in iron. In the first place the alternative explanation, that FeO (4·29) formed by the decomposition of wüstite above 480° C is improbable: if cooling above 480° C is slow enough to precipitate iron and form FeO (4·29) then cooling through the 480° C zone cannot be fast enough to prevent the complete decomposition of all wüstite not already transformed at higher temperatures; so that FeO (4·33) can only be formed if cooling through 480° C and higher temperatures is fairly rapid and the cooling curve flattens out below 480° C. Second, the formation of FeO (4·29) below 570° C is associated with the precipitation of iron, FeO (4·33) with magnetite. All the X-ray films showed the magnetite pattern, but no free iron was detected. This would suggest that the FeO (4·33) has formed below 480° C and that the FeO (4·29) had been present before cooling started. It is of course possible that the precipitate is too fine to yield detectable lines on the X-ray pattern and that all the magnetite lines come from primary or pro-eutectoid crystals, so that no definite conclusion can be reached from X-ray evidence alone. However, there is a third line of reasoning which tends to confirm that it is the oxygen-rich wüstite FeO (4·29) which was present in the hot 'equilibrium' scale. In the normal three-layer scale, the wüstite is in equilibrium with metal, and therefore saturated with iron, on one interface and in equilibrium with magnetite, and therefore saturated with oxygen, on the other. Thus two extremes of concentration are present on two opposite surfaces of a layer and a linear concentration gradient should be set up. Engell[6] has shown experimentally that such a linear concentration gradient does indeed occur in wüstite grown in direct contact with the metal substrate, but that in many scales a gap separates the wüstite from the underlying metal, leading to saturation of the entire wüstite layer with oxygen. A wüstite layer with a linear concentration gradient would contain material of all parameters between 4·29 Å and 4·33 Å and the X-ray pattern should show very broad and diffuse lines. The presence of sharp doublets, one line of which is due to transformation in cooling, indicates that the other line represents wüstite of unique composition. Micrographic evidence, which will be discussed in detail below, confirms that the scales have many of the characteristics of oxides separated from the substrate during part of the oxidation process; one such characteristic is saturation of the wüstite with oxygen. In spite of the absence of rigid proof, it seems reasonable to conclude that any FeO (4·29) found in the X-ray pattern originated in the scale as grown, while FeO (4·33) formed during subsequent dissociation on cooling.

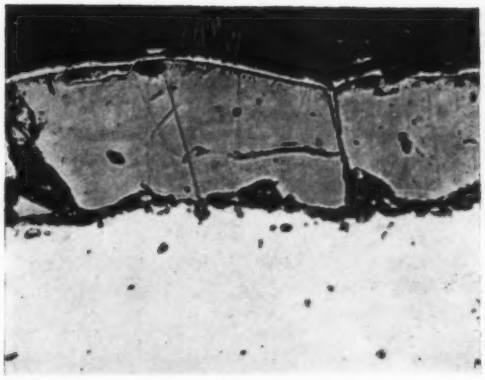
Metallographic examination tends to support the view that some of the wüstite has formed as a result of transformation below 480° C. The evidence is not conclusive however, and will be referred to in connection with the empirical examination of the various scale samples.

It is generally held that rapid cooling of hot-rolled products improves the rate and quality of pickling to a greater extent than can be fully accounted for by the decrease in the amount of scale formed.[24] Full decomposition of wüstite to magnetite and iron rarely occurs at practical cooling rates, so that its suppression cannot explain the benefits of accelerated cooling. The present work indicates that variations in cooling rate influence the composition of the wüstite and the extent of precipitation of a second phase, and these factors may have some effect on pickling.

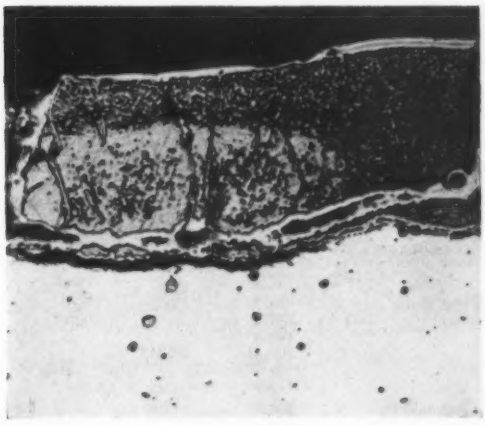
Scale on billets

Estimates of the amount of scale present on the billets are given in Table II. It has been indicated that ammonium citrate pickling dissolves more metal and gives incorrectly high weight-loss figures; in iodine stripping on the other hand, some oxide is lost so that the oxide weight figures are rather low. The extent of these errors has not been investigated in detail; in the table the values obtained by the two methods have been averaged and the figures rounded off as a crude approximation. Evidently a large number of experiments would be required to provide a satisfactory impression of the amount of scale on the billets. However, the figures in Table II serve to indicate that the billets have lost scale during reheating and cropping. It is possible that some scale spalls off when cold billets are charged into the furnace, but the most likely reason for spalling is a spray of cooling water at the cropping shear and the chance that the cropped samples were dragged through puddles of water on the mill floor.

The scale on hot-rolled billets is shown in Figs.2 and 3, that on reheated billets in Figs.4 and 5. It is obvious at first sight that the scale on the latter specimens is appreciably thinner and that there are considerable fluctuations in scale thickness between similar specimens. This confirms the weight-loss observations described above. All the scales show variants of the fundamental three-layer structure; Fe_2O_3 is present on the outer surface of all specimens, though the amount varies considerably. If, as seems



4 *Billet B, reheated, typical structure* × 500



5 *Billet B, reheated, local decomposition of wüstite* × 500

likely, the reheated samples lost a considerable proportion of their scale by spalling after removal from the furnace, only a substantial approach to equilibrium with the atmosphere during cooling can account for the presence of an Fe_2O_3 layer. The scale/metal interface is fairly smooth, with rather more serrations on the hot-rolled billets. Penetration of oxide is very slight, in agreement with the observations of Moreau and Cagnet,[15] on OH mild-steel billets.

The main feature of the scales in Figs.2–5 is severe fissuring, both parallel and transverse to the surface, and this has had a profound influence on the structure. The three oxides of iron are present: There is a thin layer, often disrupted, of ferric oxide on the surface of the scale; this is followed by a thicker layer of magnetite; the bulk of the scale consists of wüstite characterized by the pro-eutectoid precipitation of magnetite. Many of the fissures in the wüstite have permitted gaseous oxygen to react with the scale, so that they are bordered by a thin seam of magnetite.

Although the scale in Fig.3 is much thinner than that in Fig.2 which was presumably formed under similar conditions, it shows evidence of more severe oxidation: the ferric oxide and magnetite layers are much thicker; the wüstite layer is separated from the underlying metal by a wide gap and this has produced an exceptionally wide magnetite border on the inside of the wüstite layer; throughout the wüstite layer magnetite particles coarse enough to establish their pro-eutectoid origin are uniformly distributed, indicating that it had been saturated with oxygen. In contrast to this, the inner border of magnetite on the wüstite in Fig.2 is extremely thin and pro-eutectoid magnetite precipitation indicates oxygen saturation over roughly half the thickness of the wüstite layer; further in, the amount of magnetite diminishes gradually and there is quite a wide band of wüstite free from precipitate. It requires no emphasis that the scale in Fig.3 cannot have been formed under more severely oxidizing conditions than that in Fig.2 or it would be thicker rather than thinner.

Engell and Wever[11] have compared the characteristics of scale growing directly on an iron substrate with those of scale separated from the metal core by a gap which does not permit oxygen to react directly with the metal surface but prevents iron from diffusing into the scale. Oxygen diffuses inward from the outer surface but no iron enters the scale at the interface with the metal. This has two effects: oxidation of iron is interrupted so the scale layer is thinner; and the oxygen content of the scale increases so that the proportion of higher oxides increases and the wüstite is saturated with oxygen.[6]

The differences between Figs.2 and 3 bear a close resemblance to the differences between adherent and separated scales but there is the additional feature that the gaps have allowed oxygen to enter. Certainly the scale in Fig.3 has all the characteristics associated with a gap between the oxide and the metal substrate. However, the scale in Fig.2 is demonstrably not an adherent layer; there is an obvious gap between the oxide and the metal core and the border of magnetite confirms that this gap is not due to mechanical damage during preparation of the specimen. The fact that saturation with oxygen has progressed roughly halfway across the wüstite layer suggests that the consequences of separation from the substrate had not had an opportunity to reach equilibrium, i.e. that the gap formed fairly late in the course of oxidation. Thus the differences between the two scales suggest that the gap in Fig.3 appeared fairly early in the history of the formation of the scale, while separation of the scale in Fig.2 from its substrate occurred much later.

It is postulated that fissures were formed in both scales during hot rolling but that those in Fig.2 were healed during oxidation on the cooling bed, leaving transverse magnetite seams in the wüstite; the gap between the scale and the steel must have formed fairly late in the course of cooling, perhaps as a result of thermal contraction of the steel. No definite explanation can be offered why the gap should be bridged and healed in one case and not in another. It is possible that when the sides of adjacent square billets touch each other on the cooling bed, access of oxygen is inhibited and healing cannot proceed, while the exposed faces of the billets can react freely with the atmosphere. For the present, healing of defects in scales can be regarded as a random process which might repay further study.

According to Table I the scale on billet *A* before reheating consists predominantly of FeO (4·33), together with some magnetite. Figure 2 shows that

TABLE III Amount of scale on rod surface

	Billet	Weights of scale removed chemically: Weight of scale removed mechanically, g/m²	Ammonium citrate method, g/m²	Iodine method, g/m²	Electrolytic NaOH method, g/m²	Total weight of scale, g/m²	Total weight of scale, g/m² of original area	% scale by weight of specimen	% scale removed mechanically
⅜-in. rod at stand 10	A	172·3	43·2	...	...	189·0	801·0	0·665	87·0
		157·0	...	5·5	...				
	B	195·8	78·2	...	...	240·5	1016·0	0·85	82·3
		200·0	...	7·0	...				
5 swg rod, last wrap at reels	A	77·2	38·3	...	...	87·5	949·0	0·79	77·9
		58·9	...	0·6	...				
	B	67·3	20·3	...	...	85·5	850·0	0·77	81·8
		72·4	...	1·1	...				
5 swg rod, front of cold coil	A	88·3	(30·2)	...	...				
		127·3	...	(0·7)	...				
		103·8	...	...	9·4	113·2	1228·0	1·03	91·6
	B	103·3	(38·4)	...	...				
		104·8	...	(0·7)	...				
		113·9	...	...	9·0	122·9	1220·0	1·11	92·7
5 swg rod, middle of cold coil	A	290·6	(45·4)	...	...				
		435·0	...	(1·0)	...				
		233·5	...	...	7·5	241·0	2615·0	2·19	96·8
	B	341·5	(39·5)	...	...				
		360·0	...	(2·0)	...				
		298·0	...	...	6·0	304·0	3022·0	2·79	98·0
5 swg rod, back of cold coil	A	95·0	(31·2)	...	...				
		99·5	...	(2·5)	...				
		55·0	...	...	6·8	61·8	670·0	0·56	89·0
	B	68·4	(30·1)	...	...				
		116·0	...	(1·0)	...				
		97·5	...	...	5·7	103·2	1027·0	0·93	94·5

the magnetite is present in two forms: as a continuous outer layer having some Fe_2O_3 on its outer surface, and as a precipitate in the thick wüstite layer. The latter is roughly bisected by a line of coarse magnetite crystals which tends to run parallel to the metal/scale interface. Columns of similar coarse crystals run from this line in the direction of the coherent magnetite layer. The remainder of the magnetite precipitate is much finer. It is scattered fairly densely in the outer zone where coarse precipitate is also present and rather more loosely in the inner zone, leaving an inner band of wüstite substantially clear of magnetite.

It has already been pointed out that the scale on the reheated billets is extremely variable in thickness and structure; often the outer layer or the entire scale appears to have spalled off. A representative field is illustrated in Fig.4 There are numerous cracks in the scale, some of them manipulative in origin, to judge from the absence of a magnetite seam. Figure 5 shows a very complex structure which can be found in this scale, although it does not occur very frequently. The bulk of the scale in these selected zones consists of wüstite entirely surrounded by magnetite seams. There is a continuous outer layer of Fe_2O_3 which extends locally to the borders of transverse cracks. The gap between the scale and substrate contains several narrow seams of magnetite, suggesting repeated healing and re-opening of the gap. The pro-eutectoid magnetite is present mainly in the form of very narrow columns extending across the wüstite layer. Two distinct areas of wüstite can be distinguished: in one the wüstite is dark-etching and contains a very fine magnetite precipitate, in the other zone the wüstite is much lighter and contains somewhat coarser particles which have etched up like the dark wüstite rather than magnetite.

The dark-etching structure with its barely resolvable precipitate is found in scattered zones in the scale on billets taken from the reheating furnace. It may well have formed by the decomposition of wüstite below 480° C into FeO (4·33) and magnetite. No FeO (4·33) was found in the X-ray examination of the scale on billet *B* after reheating, although the dark-etching wüstite was found on micro specimens from this billet. It was only present in small amounts, however, and may well have been masked by the quantity of other constituents in the scale; this has certainly happened to the Fe_2O_3 which could not be detected in the X-ray films but which can be identified without hesitation in the photomicrograph (Fig.5). The scale on the hot-rolled billets contains much more FeO (4·33) than that on samples from the billets after removal from the reheating furnace (Table I), but the microstructure identified in Fig.5 as a mixture of FeO (4·33) and magnetite is absent from Figs.2 and 3. Slight differences in the etching characteristics of the wüstite can, however, be detected in Fig.2. The pro-eutectoid magnetite has a halo of lighter-etching wüstite, the remainder of which has etched a little darker. This dark-etching effect may be due to submicroscopic particles of magnetite embedded in FeO (4·33).

Scale on rod

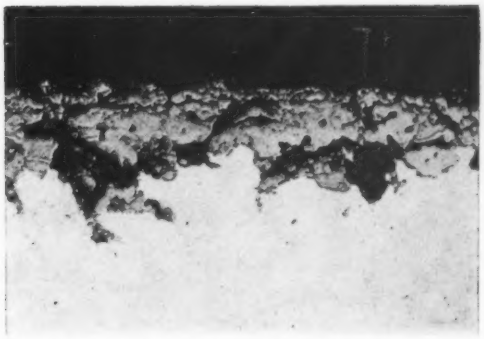
The results of weight loss determinations by various methods of scale removal are presented in Table III. The figure for the total weight of scale is the sum of the amounts removed mechanically and chemically. The best available values for chemical removal are used in each case: the values for chemical scale removal not employed in estimating total scale weights are given in brackets; they are not omitted entirely because the corresponding values for mechanical removal from the same specimens give a useful indication of the scatter of results. This is rather large, but still less than for scale removal by chipping from billet surfaces (cf. Table II).

6 *Rod A, § in. dia., at stand 10* ×500

The total amount of scale per unit surface area is much smaller on the §-in. rod at stand 10 than on the billets (cf. Table II), and diminishes further in the 5 swg rod at the reels. The samples of rod taken from the cold coil, however, show an increase in the total amount of scale, which is especially pronounced in the samples taken from the middle of the coil. This variation in the amount of scale corresponds to differences in cooling rate: the heaviest sections took longest to cool; the §-in. rod sample cooled a little more slowly than the 5 swg rod sample at the reels; the cooling rate of the coil was much slower than that of samples cut off in the mill, and the ends of the coil cooled more rapidly than the middle. It seems reasonable to conclude that the cooling rate is the principal factor in determining the amount of scale formed.

X-ray examination of the phases present in the scale (Table I) indicates that the formation of FeO (4·33) had proceeded furthest where the cooling rate was slowest. Thus the structure, as well as the thickness, of the scale is a sensitive function of the cooling rate.

To emphasize the importance of surface area the total weight figures have been converted to scale weights per unit area of initial billet surface. This method of presentation brings out the part played by the furnace scale originally present on the billet before rolling and the relative importance of scale formation during and after hot rolling; if the furnace scale remains on the surface and no fresh scale is formed, the weight of scale per square metre of initial billet surface should remain constant through all stages of rolling. The experimental results in Tables II and III demonstrate the loss of furnace scale in the rolling mill and the formation of fresh scale, especially after rolling is complete when the coils of rod cool in air. The billets are in the reheating furnace for a considerable time and a substantial scale layer builds up at the surface, but a substantial proportion is lost through spalling. The §-in. rod at stand 10 shows a gain in scale, particularly in the case of billet *B*; the 5 swg rod at the reel shows an increase in oxide on



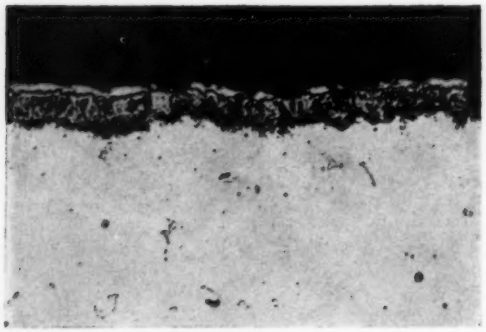
7 *Rod B, 5 swg, last wrap at reels* ×500

billet *A*, a loss on billet *B*. Scale may be lost by spalling in the mill, while more scale grows during cooling, and rolling has extended the surface area sufficiently to counteract the effect of increased cooling rate. In the samples cut during rolling and cooled freely in air these two processes are roughly balanced, with a slight tendency to favour scale growth during cooling. In the samples cut from the cold coil however, the amount of scale is significantly increased, and the growth of scale on the rod in the middle of the coil is so great that in this case at least the effect of slow cooling greatly exceeds any random fluctuations.

The results indicate that the scale present at any stage in the rolling operation is made up partly of furnace scale and partly of fresh scale, that the proportions vary widely and randomly, and that substantial amounts of the furnace scale are lost at different points in the rolling mill. On the final rod, any residual furnace scale represents a very small proportion of the total; so much scale is formed after the final roll pass that any furnace scale remaining on the surface would be undermined by subsequent oxidation.

Rolled-in furnace scale would produce a very rough oxide/metal interface, which tends to be smoothed out by subsequent oxidation. This may account for the fact that the proportion of scale removed by plastic deformation of the rod was significantly greater with samples taken from the cold coil, particularly those from the middle of the coil. It is also possible that thinner scales are more adherent during deformation, although the effect of scale thickness is easier to appreciate when the rod is descaled by bending rather than in tension.

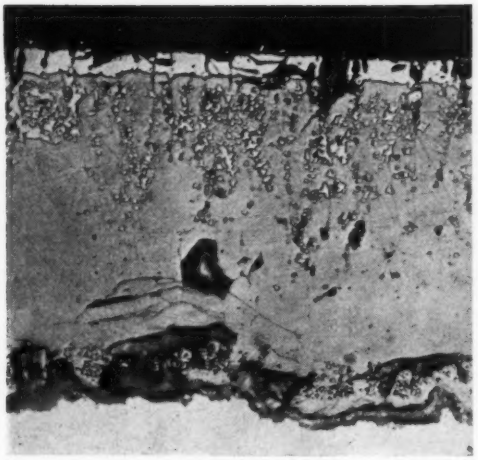
The overall tendency for the degree of oxidation to increase outwards through the thickness of the scale might be modified but could not be invalidated by the presence of gaps between the scale and the substrate and of transverse cracks in the scale. This tendency is not reflected in differences in the proportions of the various phases present in the scale removed mechanically and by iodine stripping. The fraction of scale which has adhered to the rod during plastic deformation and was subsequently removed by iodine stripping contains as high a proportion of the higher oxides as the fraction that spalled off. The gap between scale and substrate appears an obvious plane of separation but any gap capable of influencing the oxygen distribution in the scale must have formed



8 *Rod A, 5 swg, front of cold coil* ×500

before oxidation was complete and the surface of the metal beneath the gap must therefore be covered by a thin oxide film formed under conditions of adherent growth, i.e. it should show diffuse FeO lines; since these were not found, any material formed by oxidation across the gap must be swamped in the iodine-stripped sample by oxide from the bulk scale. Adherent bulk oxide can be formed locally if scale growth is not disturbed by a gap, but the scale so formed has a lower oxygen content and a lower proportion of magnetite and if it adheres to the surface during plastic deformation it should be distinguished in the iodine-stripped sample. In fact, the only sample with less magnetite than the remainder was one from the middle of coil *A* which had been removed mechanically. The results suggest that scale comes off in flakes comprising all layers of oxide and that there is very little tendency for the inner layer to adhere to the substrate preferentially: it follows that adhesion of the oxide to the substrate is much weaker than the cohesion of the scale. Evidently the mechanical strength of adhesion of the oxide to the substrate is low; this facilitates both formation of a gap during oxidation and spalling during plastic deformation.

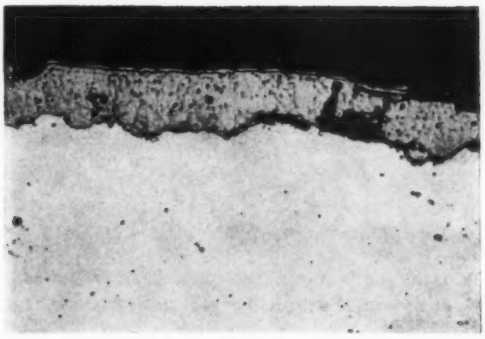
A small fraction of oxide adheres to the surface after plastic deformation. This is shown in Table III, and has been observed by other investigators using less severe tensile straining[18] and commercial scale breakers.[26] This adherent fraction presumably consists of small patches of oxide equal in thickness to the original scale. The deformed wire should have a metallic surface contaminated by oxide debris over most of its area, with small blocks of thick scale at isolated points; this is confirmed by the appearance under the microscope of sections of mechanically descaled wire. Evidently the scale is anchored to the substrate at isolated points during plastic deformation of the rod. Spalling occurs by shear at the interface and transverse cracking of the scale. The thicker the scale, the higher the stress at which transverse cracking occurs and the larger the flakes which spall off. During plastic deformation of the rod, small flakes might tend to move with the surface while large ones would sustain a great deal more lateral shear; if the distribution of 'anchoring points' is uniform, a larger proportion would be sheared if the scale is broken up into large flakes, while smaller oxide flakes might adhere. It seems possible, therefore, that the tendency to spall during plastic deformation increases with scale thickness in tension as well as in bending.



9 *Rod A, 5 swg, middle of cold coil* ×500

Consideration of the nature and distribution of the anchoring points is bound to be very speculative. The effect of the orientation relationship between wüstite and the substrate may be worth investigating; it is conceivable that the presence of wüstite influences the γ–α transformation at the surface and that the freshly formed ferrite affects the wüstite produced by continued oxidation at the interface below Ar_1. The influence of surface roughness and the coherence of rolled-in scale at laps and other rolling defects would also be of interest. If a smooth interface has fewer anchoring points, as seems likely, slow cooling after rolling, which allows oxidation to undermine rolled-in scale, would facilitate spalling. Evidently both explanations for the high proportion of mechanically removed scale on samples from the middle of the coil (Table III), e.g. thicker scale or smoother interface, are physically tenable.

The thickness of the scales in the photomicrographs of sections from various rod samples, Figs.6–10, agrees with the scale removal measurements. Microexamination also supports the deduction from the results in Table III that the interface on the $\frac{5}{8}$-in. rod at stand 10 and on the last wrap of 5 swg rod at the reels is more serrated than on samples from the cold coil. The microstructures also confirm the X-ray results in Table I and complement them in showing traces of hematite (Figs.6 and 7) which could not always be detected in the X-ray patterns. The particle size of pro-eutectoid magnetite (Figs.8 and 9) corresponds to the finer precipitate in the scale on the billets (cf. Figs.2 and 3); presumably the particle size is a function of the temperature of precipitation. The gap between the scale and subscale has no magnetite border. Evidence of atmosphere penetration into the gap is afforded by the precipitation of pro-eutectoid magnetite in the wüstite adjoining the gap; either oxygen has diffused into the wüstite from the gap but has not saturated it, suggesting that the scale split off the substrate very late in the course of oxidation, or splitting occurred early and subsequent oxidation has partially bridged the gap and allowed iron to diffuse into the wüstite and re-establish a concentration gradient.



10 *Rod A, 5 swg, back of cold coil* ×500

Random differences in the thickness of the magnetite layer and the amount of pro-eutectoid magnetite can be observed on samples of comparable history. The front and back of coil *A* after cooling (Figs.8 and 10) exemplify this point. The scale illustrated in Fig.10 was probably formed by uninterrupted growth, while that in Fig.8 has evidently separated from the substrate in the course of oxidation.

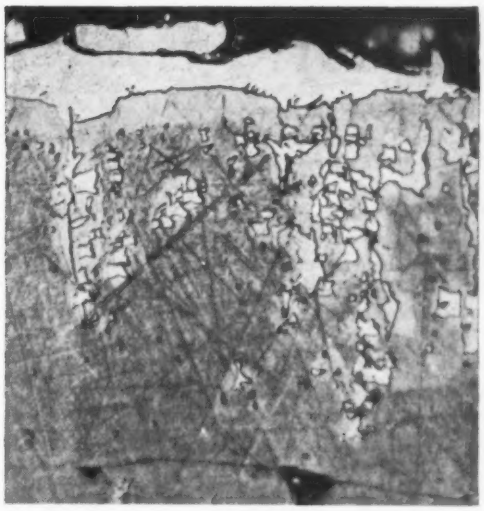
According to the X-ray evidence in Table I the decomposition of wüstite below 480° C has not progressed as far on the rod samples as in the hot-rolled billet scales. The metallographic evidence consists of local differences in the depth of etching rather than the sharply defined two-phase structure illustrated in Fig.5. An example is shown in Fig.11, where the magnetite layer and precipitate are bordered by light-etching wüstite which contrasts quite sharply with a darker-etching wüstite matrix. An extremely high magnification has been chosen in an attempt to reveal the presence of a precipitate in the dark-etching wüstite. It seems reasonable to identify the latter with FeO (4·33); this lends some support to similar reasoning about the scale on hot-rolled billets where the etching effect is not quite so sharp (Fig.3).

It can be concluded that the separation of scale from the metal during oxidation as well as differences in cooling rate between samples produce consistent effects on the structure of the scale which can be detected by combining metallographic and X-ray techniques and which exert a considerable influence on the thickness and adhesion of the scale. The way other properties, particularly the response to pickling, are affected by these variables might repay intensive study.

CONCLUSIONS

A systematic study of scales by a combination of techniques can provide a great deal of information about the effect of mill practice on oxidation.

Wüstite of two discrete parameters was found on all the scales. FeO (4·29) is saturated with oxygen and is believed to predominate at the temperature of oxidation. The rates of cooling under mill conditions were fast enough to suppress the eutectoid decomposition of wüstite at 570° C, but some transformation occurred, probably below 480° C, leading to the precipitation of FeO (4·33) in amounts which increased at slower cooling rates. Isothermal transformation below 480° C leads to a gradual growth of the parameter of all the wüstite and the formation of



11 *Rod A, 5 swg, halo of light-etching wüstite around magnetite* ×1500

discrete crystals of FeO (4·33) in a matrix of FeO (4·29) has not been observed in previous work; it is attributed to inoculation by incipient transformation at 480° C during continuous cooling, facilitated by the high oxygen concentration of the wüstite. The predominance of FeO (4·29) in the scale ' as grown ' is evidence of separation of the scale from the substrate during oxidation. Many of the samples show a gap at the scale/metal interface and magnetite borders round various fissures, indicating penetration of the atmosphere.

The rate of cooling of various mill products is sensitively reflected in the thickness and structure of the scale. A substantial proportion of the furnace scale is lost in processing. The bulk of the scale on the finished rod has formed during cooling of the coil after reeling. Any residual furnace scale is undermined by this oxidation in air; equilibrium between the remnants of the furnace scale and the fresh oxide is attained very rapidly and the scale/metal interface is substantially that produced by the inward growth of oxide during cooling. The effect of surface defects produced in rolling, and of oxide rolled deeply into the surface, requires further investigation; it may play an important part in determining the adhesion of the scale to the surface of the steel.

Adhesion of the scale during plastic deformation of the underlying metal depends on the thickness of the scale and the density of sites where the oxide is more firmly anchored to the metal. The thickness of the layer increases the transverse strength of the scale, reduces the tendency to transverse cracking, and thus increases the size of coherent flakes; the larger is the flake the greater is the distance between ' anchoring points ' held rigidly by the cohesion of the scale while the metal surface is strained, i.e. the greater is the effective shear displacement at anchoring points. The distribution of anchoring points may depend on the prevalence of defects where scale has been rolled into the surface of the metal. Slow cooling at fairly high temperatures produces a thicker scale and may also afford an opportunity for further oxidation to

undermine such defects and produce a smoother interface; it may also tend to heal gaps between the scale and substrate.

ACKNOWLEDGMENTS

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REFERENCES

1. L. B. Pfeil: *JISI*, 1929 (I), 501–547.
2. K. Heindlhoffer and B. M. Larsen: *Trans. Amer. Soc. Steel Treat.*, 1933, **21**, 865–895.
3. J. Benard and O. Coquelle: *Comptes Rendus*, 1946, **222**, 796–797.
4. L. B. Pfeil: *JISI*, 1931 (I), 237–255.
5. J. Paidassi: *Acta Met.*, 19, **3**, 447–451.
6. H. J. Engell: *Arch. Eisenhüt.*, 1957, **28**, 109.
7. G. Chaudron and H. Forestier: *Acad. Sci.* (France), 1924, **178**, 2173.
8. W. A. Fischer, A. Hoffmann, and R. Shimada: *Arch. Eisenhüt.*, 1956, **27**, (8), 521–529.
   W. A. Fischer and A. Hoffman: *ibid.*, 1958, **29**, 107–113.
9. A. Dravnieks and H. J. McDonald: *J. Electrochem. Soc.*, 1948, **94**, 139–151.
10. B. W. Dunnington, F. H. Beck, and M. G. Fontana: *Corrosion*, 1952, **8**, (1), 2–13.
11. H. J. Engell and F. Wever: *Acta Met.*, 1957, **5**, 695–702.
12. A. Preece, G. T. Richardson, and J. W. Cobb: Second Report of the Alloy Steels Research Committee, Section III, Part 1, 9–63.
13. B. Ilschner: *Arch. Eisenhüt.*, 1956, **27**, 337–342.
14. J. Moreau: *Rev. Mét.*, 1956, **56**, 703–714.
15. J. Moreau and M. Cagnet: *ibid.*, 1957, **57**, (5), 383–402, cf. *Metal Treatment*, 1957, **57**, 362–374, 407–415, 456–458.
16. W. Dahl and W. Lueg: *Stahl Eisen*, 1957, **77**, 845–853.
17. H. J. Engell and F. K. Peters: *Arch. Eisenhüt.*, 1957, **78**, 567–574.
18. S. Garber: Private communication.
19. L. Wetternik: *Korros, Metallchem*, 1942, **8**, 130–134; *cf.* O. Kubaschewski and B. E. Hopkins, 'Oxidation of metals and alloys', 90, 1953: London, Butterworth Scientific Publications.
20. W. H. J. Vernon, F. Wormwell, and T. J. Nurse: *J. Chem. Soc.*, 1939, 621–632; *JISI*, 1944, (2), 81P–92P; J. T. Nurse and F. Wormwell: *J. App. Chem.*, 1952, **2**, 550–554.
21. G. Croall and A. D. Hopkins: Unpublished work.
22. E. R. Clark and B. Farrell: Private communication.
23. A. D. Hopkins and J. V. Hardy: *Metallurgia*, 1955, **51**, 209–211.
24. E. L. Knapp: *Wire Wire Prod.*, 1956, **31**, 873–877.
25. B. T. M. Willis and H. P. Rooksby: *Acta Cryst.*, 1953, **6**, 827–831.
26. C. Eisenhuth: *Stahl Eisen*, 1957, **77**, 324–334.
27. L. S. Darken and R. W. Gurry: Metals Handbook, 1948, 1212: Cleveland, Ohio, USA, American Society for Metals.
28. R. Collongues, R. Sifferlen, and G. Chaudron: *Rev. Mét.*, 1953, **50**, 727–736.

News of Special Reports

THE MOST RECENT addition to the Special Report Series of The Iron and Steel Institute is No. 66, the Sixth Report of the Corrosion Committee. This is an account of the work of the Committee, which was founded in 1928, during the past twenty years, since the appearance of the Fifth Report in 1938. It has been compiled by Dr J. C. Hudson of BISRA, who has been associated with the Committee since its earliest days.

The Report deals with three main topics: atmospheric corrosion, atmospheric corrosion and protection at elevated temperatures (up to 300°C), and marine corrosion service trials. In addition, there is a survey of the Committee's work since 1938, which includes an account of the fundamental research carried out at Cambridge under the direction of Dr U. R. Evans, F.R.S.

A joint meeting of The Iron and Steel Institute and the Corrosion Group of the Society of Chemical Industry is being held on 15 October to discuss the Report; full details of the meeting are given in the News section.

Copies of the Report may be obtained from the Secretary, price £3 3*s*. It consists of 228 pages in octavo format, and is bound in stiff board covers; there are many illustrations in the text.

Two further reports are to be issued by the end of the year. The first of these, No. 64 in the series, is the full report of the conference on precipitation processes in steels, held at the University of Sheffield in July 1958. Over 150 scientists from ten different countries attended this conference, and its proceedings will be of the greatest value to those interested in this important subject.

The other report in preparation, No. 65, consists of the proceedings of the meeting of the Institute's Engineers Group held in the Netherlands in April of this year to discuss the subject of ore handling and treatment. This again was an international meeting, with papers from Canada, the Netherlands, Sweden, and the USA as well as the UK. Of particular interest are the papers describing the new ore terminal at Rotterdam and the installations at Seven Islands and Contrecœur in Canada.

The effect of alloying mild steel upon its resistance to stress-corrosion cracking

R. N. Parkins and A. Brown

SYNOPSIS

Copper-containing steels, although known to be useful in resisting certain types of corrosion, are more prone to cracking in nitrate solutions than are unalloyed mild steels. Chromium additions increase the resistance to cracking, and aluminium up to 1% prevented any grain-boundary attack under the conditions of testing employed.
1690

THE DISASTROUS intercrystalline cracking that occurs when static stresses of sufficient magnitude are applied to mild steels subjected to the action of specific corrosive media may be prevented by control of either the corrosive environment[1] or the stress.[2] The third requirement for cracking, of a steel of susceptible composition and structure, has received relatively little attention and the present work was initiated for the purpose of determining the effects of additions of Al, Cr, and Cu to mild steel. Since these elements are well known to have beneficial effects on other types of corrosion,[3,4] it was thought that they might prove effective in preventing stress-corrosion and so afford an additional or alternative means to stress relief or chemical inhibition as preventive measures.

Most of the previous work on the effect of steel composition upon its propensity towards stress-corrosion has been concerned with the influence of the carbon[5] and nitrogen[6] contents. Various workers have studied the effect of Al additions to steels to render these non-ageing, and claims have been made[6,7] that such additions are beneficial while others have shown that they are without effect.[5] However, the amounts of Al added for this purpose are usually quite small ($< 0{\cdot}1\%$) and are not regarded as resulting in low-alloy steels of the type used for their resistance to general corrosion.

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Herzog[8] has reported the results of some work on the effect of Al, with and without additions of Cr, to steels subjected to the action of nitrates. Aluminium itself had a beneficial effect when present in amounts between 0·5 and 2·0%, although complete immunity from cracking did not exist in the normalized condition. With Cr contents of between 2 and 4%, together with 0·8% Al, a bainitic structure was produced on air cooling, and in this condition, even with less than 0·1%C, resistance to stress-corrosion was observed. The same steel when water quenched failed in a stress-corrosion test in a nitrate solution.

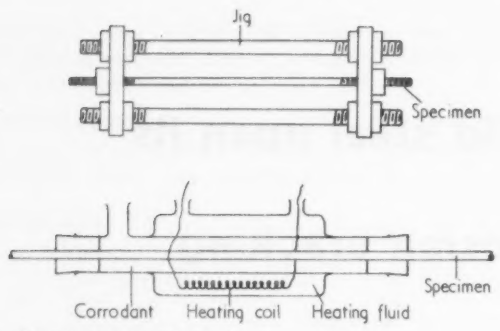
EXPERIMENTAL

Preparation of steels

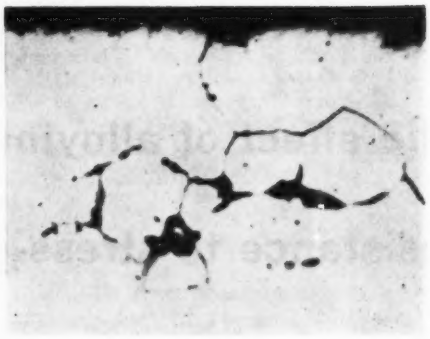
The steels were melted in a high-frequency induction furnace, using dead-soft mild-steel wire as the charge, and cast into ingots 8 in. long and $1\frac{1}{2}$ in. dia. Copper was added in the metallic state immediately after

TABLE I Analyses of steels tested

	Analyses, % C	Cu	Cr	Al	Mn	Si	Yield strength, tons/in²	U T S, tons/in²	Reduction in area, %
Unalloyed steel	0·05	0·05	0·04	0·06	0·54	0·23	14·9	24·1	70
Copper steels	0·05	0·29	...	...	0·46	0·19	18·4	26·2	70
	0·06	0·59	...	...	0·56	0·18	18·9	25·9	65
	0·05	1·02	...	...	0·51	0·24		not determined	
Chromium steels	0·06	...	0·28	...	0·62	0·17	19·8	26·0	70
	0·07	...	0·57	...	0·51	0·19	20·1	26·5	65
	0·09	...	1·04	...	0·47	0·20	20·0	26·6	65
Aluminium steels	0·05	...	...	0·30	0·52	0·21	16·9	25·0	65
	0·05	...	...	0·60	0·45	0·17	18·7	26·3	65
	0·06	...	...	1·00	0·49	0·16	19·3	26·4	55



1 *Test jig and corrosion cell*



2 *Grain-boundary penetration in 1%Cr steel tested for 1 week, unetched* ×1 000

melt-down, and Cr was added as ferrochrome immediately before final deoxidation. Final deoxidation was by Al (0·03%), after ferrosilicon and ferromanganese had been added in the required amounts. The cropped ingots were forged to 1¼ in. dia., hot rolled to ½ in. dia., pickled, and finally cold drawn to 0·19 in. dia. After cutting to a suitable length, the wires were straightened and then vacuum annealed at 965°C for 4 h. Details of the compositions of the steels are shown in Table I. The carbon content was intentionally low, in the range known to give rise to marked susceptibility to cracking.[5] Microscopical examination of each steel showed the presence of grain-boundary carbide films in every case. The higher-Cr steels were observed to contain some pearlite grains, in addition to boundary carbide. The wires were plastically extended 10% before testing.

Method of testing

The wires were stressed by restraint in a jig between two 3 in. × 1 in. × ⅝ in. beams held parallel to one another by two 11-in. lengths of ½-in. dia. steel rod bolted to the beams as shown in Fig.1. The beams contained a central hole through which the specimen passed but which retained locking nuts threaded on to the ends of the specimen. The stress was applied by subjecting the specimen to a known load in a tensile testing machine and then tightening the locking nuts so that the specimen was restrained from contracting when the externally applied load was removed. The jigs were calibrated to allow for the small strain-relief in the specimen which occurred when the strain was transferred from the testing machine to the jig.

The dimensions of the jig were chosen so that a glass cell containing the corrosive liquid could be placed round the specimen and inside the jig. The design of this cell is shown in Fig.1. It consisted of a glass tube surrounded over the mid-portion by a glass heating jacket which contained a low-voltage electric heating coil immersed in glycerol. A side arm was attached 1 in. from one end of the inner tube, through which the test solution was introduced and to which a reflux condenser was attached. The ends of the inner tube were sealed by rubber bungs, through which the specimen passed.

In preparing for a test the assembled specimen and corrosion cell were heated and the solution introduced before the stress was applied, otherwise the expansion associated with heating the specimen caused stress-relief. The time of failure of the specimen was readily determined, since after fracture the end pieces, which previously had been screwed up tight, became loose and turned easily with the fingers. After an initial test, in which the approximate time for failure was determined, replicate tests were made for the purpose of determining the cracking time to a higher degree of precision (usually 1 h).

The majority of the tests were carried out in a boiling aqueous solution containing 860 g calcium nitrate and 30 g ammonium nitrate per litre of solution. A few tests were carried out in a calcium nitrate solution containing 650 g/l., to which copper sulphate was added in varying amounts.

Electrode potential measurements

Comparative potential measurements of corroding specimens were made against a saturated calomel electrode with a recording valve voltmeter in certain experiments. The bridge between the test solution and the standard electrode was made by introducing a glass tube through one of the bungs in the end of the corrosion cell and passing a string through this tube so that one end dipped into the test solution and the other into a beaker containing a saturated KCl solution.

RESULTS

The conditions of testing for this comparative study were chosen so that the results on the unalloyed steel indicated this to be a moderately susceptible steel. It was then possible, using the same test conditions, to observe whether a particular alloying element increased or decreased cracking resistance. The results of the tests have been summarized in Table II.

TABLE II Comparison of cracking properties of steels

Steel	% Specimens cracked (minimum of 6 tests)	Average time to failure, h
Unalloyed	50	36
0·29% Cu	100	31
0·59 „	100	20
1·02 „	100	17
Cr steels	0	(*see text*)
Al steels	0	„

All tests in boiling calcium–ammonium nitrate solution at a stress of 15·4 tons/in². Maximum time of testing 500 h.

Where cracking occurred this was invariably observed, on microscopical examination, to follow an intergranular path. Although no macro-cracks were detected in the Cr-bearing steels, microscopic examination revealed the presence of grain-boundary penetration in a few areas extending to a depth of one or two grains from the surface, a typical example being shown in Fig.2. Specimens examined after various periods of testing indicated that this boundary penetration progressed with time, but at such a rate that, if continued, complete failure would have taken some 5000 h or more. The Al steels not only showed no macro-cracks, but neither did they exhibit the grain-boundary penetration observed in the Cr-bearing steels. It would appear from these results that Cu additions are detrimental from the point of view of susceptibility to nitrate cracking, Cr additions result in a greatly reduced rate of attack and Al additions prevent cracking entirely.

The results of the electrode potential measurements on the steels containing 1% of alloying element, shown in Fig.3, are in agreement with the indications of the cracking tests. The initial potentials were similar for the unalloyed, Cu, and Cr steels, whilst the Al steel was much more noble. The potentials soon altered to positions which were in the same order as the susceptibility to cracking, the most susceptible having the most anodic potential. During the tests rapid fluctuations were observed in the potentials of the plain C steel and, to a lesser extent, the Cr steel, while the Al- and Cu-bearing steels exhibited relatively smooth potential/time curves.

In considering possible explanations for the effect of copper additions to steel on the susceptibility towards cracking, it was considered that it might be useful to study the influence of a galvanic couple between unalloyed steel and copper upon the cracking tendency of the former. The copper was deposited either from the test solution by the addition of copper sulphate to the latter, or by direct plating on to part of the specimen before testing. The results of these tests are summarized in Table III. It was observed that the presence of Cu not only decreased the cracking time but also produced many more cracks in a specimen, as compared with the number of cracks which developed in the absence of Cu.

CONCLUSIONS

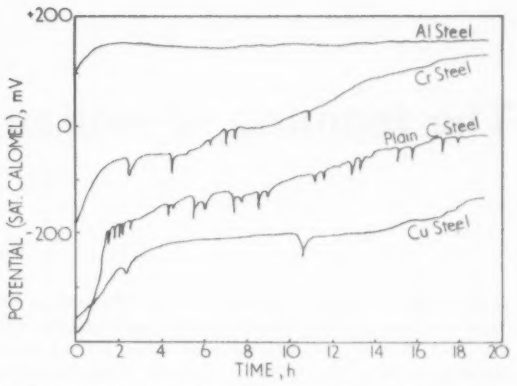
Although Cu additions to mild steels are well known to enhance resistance to corrosion under certain circumstances, the present experiments indicate that, in low-C steels, Cu may increase susceptibility towards stress-corrosion cracking in nitrate solutions. The experiments in Cu-containing solutions and with partially Cu-plated specimens indicate that Cu so coupled can enhance the cracking tendency of an unalloyed steel. If the Cu alloyed within a steel can form a galvanic couple, as by deposition after being taken into solution, then an increase in cracking tendency would be expected.

The increased resistance to cracking that results from the addition of Cr or Al places the steels in an order of susceptibility to cracking which is also suggested by the potential/time curves. The immunity from cracking of the Al steels under the conditions of testing used in the present experiments may be related to the oxide film formed on these. The observations of grain-boundary penetration in the case of the Cr steels suggest that they are not so resistant to cracking as those containing Al, although it appears likely that greater Cr additions would produce complete immunity.

TABLE III Cracking tests in presence of copper

Test condition	Average cracking time, h
8N $Ca(NO_3)_2$	36
8N $Ca(NO_3)_2$ + 0·01% $CuSO_4$	21
8N $Ca(NO_3)_2$ + 0·1% $CuSO_4$	11
8N $Ca(NO_3)_2$ + 1·0% $CuSO_4$	7
8N $Ca(NO_3)_2$. Specimen Cu plated over half of length	13

Stress = 12·4 tons/in²



3 *Potential/time curves for various steels during stress-corrosion tests*

ACKNOWLEDGMENTS

The authors wish to record their indebtedness to C. A. Parsons and Co. Ltd for drawing the wires, to Mr J. A. Hedley for assistance with some of the tests, and to the late Professor A. Preece for the provision of laboratory facilities.

REFERENCES

1. R. N. Parkins and R. Usher: to be published.
2. R. N. Parkins: *Brit. Weld. J.*, 1955, **2**, 495–501.
3. C. P. Larrabee: *Corrosion*, 1953, **9**, 259–271.
4. J. C. Hudson and J. F. Stanners: *JISI*, 1955, **180**, 271–284.
5. R. N. Parkins: *ibid.*, 1952, **172**, 149–162.
6. J. T. Waber and H. J. McDonald: 'Stress-corrosion cracking of mild steel': 1947, Pittsburgh, Pa., USA, Corrosion Publishing Company.
7. E. Houdremont, H. Bennek, and H. W. Wentrup: *Stahl Eisen*, 1940, **60**, 791–797.
8. E. Herzog: *Corros. et Anticorros.*, 1954, **2**, 3–13; 59–68, 91–98.

The foaming of molten silicates

C. F. Cooper and J. A. Kitchener

SYNOPSIS

A critical examination of the literature concerning foaming of silicate slags shows that no satisfactory conclusions can be drawn as to the fundamental cause. Laboratory experiments have therefore been carried out on synthetic $CaO–SiO_2–P_2O_5$ *melts. These have shown that foaming is absent with binary* $CaO–SiO_2$ *melts but is marked when* P_2O_5 *is added to melts containing more than 50% of* SiO_2. *The foam stability increases with* (a) *the proportion of* P_2O_5 *(in the range 0–1·8%),* (b) *the proportion of* SiO_2 *(50–63%), and* (c) *decrease of temperature.*

Surface tension measurements have been made by the maximum bubble pressure method, using a molybdenum jet, and these show that both SiO_2 *and* P_2O_5 *are surface-active components. The composition of the surface layers has been calculated for the* $CaO–SiO_2$ *melts.*

A tentative theory of foaming in this system is based on the assumption that the P_2O_5 *is responsible for a degree of surface elasticity, which, however, is insufficient to sustain foaming unless the melt is viscous (i.e. of low* $CaO : SiO_2$ *ratio and at relatively low temperatures).*

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THERE ARE OCCASIONS in the refining of steel by the basic open-hearth process when the gases liberated by the oxidation of the carbon in the steel fail to break through the slag and cause it to foam. The formation of foam has several adverse effects. One is that it increases the diffusion path of the FeO between the slag and metal since the diffusion takes place through thin films of slag. The blanket of foam also acts as a heat insulator and reduces the transfer of heat from the firing gases to the metal bath. Both of these effects prolong the refining period. The froth can also cause the firing flame to be deflected towards the furnace roof and result in breakdown of the refractories.

Methods used industrially to combat the slag foams are largely empirical, and literature relating to this problem is very sparse and consists mainly of works observations. The experiments described below were carried out in an attempt to determine the conditions under which foam is formed and to compare the physical chemistry of the silicate foams with that of aqueous foams. A brief review of the information available in the literature is given first.

PREVIOUS OBSERVATIONS

Chemical composition

Because of the highly variable nature of steel-refining slags, a comparison of the compositions of foaming and non-foaming slags is not easy to make. A typical slag may contain four or more major components together with many minor constituents not normally accounted for in analysis. Since only traces of a substance are required to cause foaming of aqueous solutions it seems possible that trace constituents in a slag may be sufficient to cause it to foam. Analyses which are available are not sufficiently detailed to permit conclusions to be drawn as to the nature of the foam-stabilizing agent; however, they do permit observations to be made upon the concentration of some of the major components in a foaming slag.

Although there are conflicting reports in the literature it is generally agreed that a high silica content (or a basicity less than 2) is favourable to foaming.[1–7] The possible part that silica may play in the stabilization of the foam are discussed later. Ferrous oxide appears to have some effect upon the foaming ability of a slag.[1] It is difficult to draw any conclusions about the percentage of FeO in foaming slags since it is very much dependent upon the lime, alumina, and silica contents. The influence of the FeO may lie in its ability to increase the oxidizing power of the slag, resulting in a greater gas evolution, rather than in any effect it has upon the physical properties of the melt. Thus the role of FeO in foaming slags is probably not that of stabilizing the foams, but only of influencing the volume of gas and the rate at which it is produced.

Speith and Heinrichs[8] made some measurements of the foam stability of synthetic $FeO–SiO_2$ slags and found that foaming was first noticeable at about 39%SiO_2 and that the stability increased up to about 65%SiO_2. Unfortunately no details were given of the manner in which the foams were produced.

The carbon content of the steel bath is said to influence the foaming of the slag. Evans[9] stated that foaming subsides when the carbon content of the steel drops below 0·2–0·3%. It is probable that, as with FeO content of the slag, the carbon content controls to some extent the rate and volume of gas evolution but does not contribute to the stabilization of the foam.

Charges containing chromium appear to be particularly troublesome in causing foaming. Woytt[7] attributed this to an increase in viscosity and a lower melting point of the slag. Kozakevitch[10] quoted the work of Layka and Koner who found that when the Cr_2O_3 is in solution in the slag the viscosity is not

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greater than about 10 poise. More often the Cr_2O_3 was not in solution, but a heterogeneous mixture was obtained and in these cases the viscosity was remarkably high. With these slags the contribution to the foam stabilization may be made by the presence of solid particles, which sometimes greatly increase foam stability but, in any case, high viscosity favours slow decay of foams.

Physical properties

A high surface tension of a slag is often supposed to contribute to the stabilization of a froth formed from it. The idea is largely erroneous since from energy considerations alone it can be seen that surface tension in itself tends to destroy the foam, by making the liquid in it tend to adopt the smallest possible surface area. Industrial observations to the effect that foaming slags have a higher surface tension than non-foaming slags are probably incidental, the difference arising from difference in composition of the various slags. Fellcht[1] obtained values between 390 and 460 dyn/cm and 340 and 370 dyn/cm for the surface tension of foaming and non-foaming slags respectively. Generally the surface tension of siliceous melts decreases with increasing silica content[6,11] and, since acid slags are more prone to foaming, it is to be expected that foaming slags would have lower surface tensions than non-foaming. However, Fellcht stated that foaming slags contain about twice as much FeO as non-foaming; therefore it is possible that the high surface tensions of the foaming slags he observed were a result of the high FeO content, since, as shown by Kozakevitch, it has a high surface tension (585 dyn/cm) as compared with SiO_2. Insufficient data are available to confirm this theory.

The viscosity of foaming slags is usually high.[1,3] Again this is to be expected if foaming slags have a high SiO_2 content, since the viscosity of binary metal-oxide–silica melts increases with increase in silica content.[13,14] It is improbable that a high viscosity is the primary cause of a stable foam, but if a stabilizing factor exists in the slag then a high viscosity should play an important part by its effect on the drainage rate of the froth. Kozakevitch[6] has discussed the work of Appen with gaseous dispersions formed in very viscous media (syrup). Appen established that bubbles in such a liquid seldom coalesce, yet with a more fluid system the bubbles readily merge, causing breakdown of the dispersions. As pointed out by Kozakevitch, slags are very fluid compared with the liquids used by Appen and hence viscosity is not likely to be the only cause of foam formation. However, with very small bubbles a dispersion could arise in a slag and could have a long life. If this is the situation which arises with some so-called foaming slags, the mechanism of formation of the bubbles and the fluid dynamics of the slag–gas system must be considered.

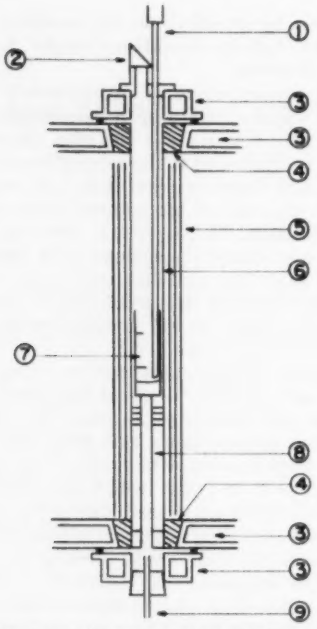
It has been observed that temperature has a marked effect on foaming. Again the evidence is conflicting but generally it appears that increase in temperature has an adverse effect upon foam stability. This could arise either from a decrease in viscosity of the slag, permitting faster drainage from the froth, or from the effect of temperature upon the foam-stabilizing properties of the slag. The contradictory reports may arise from the fact that rise of temperature could increase the rate of gas evolution by its effect on the reaction rate, and hence under certain conditions might lead to an increase in foaming.

It has been suggested by Kozakevitch[6] that the stability of slag foams is due to the structure of the interfacial layer between gas and slag; the stabilizing influence was attributed to the adsorption of SiO_2 into the surface and it was implied that P_2O_5 may contribute to the structure of the surface layer and aid the foam stabilization. If the froths observed are true foams and not simple dispersions then there can be little doubt that their stability must arise from some such surface effects. A discussion of the possible surface structures and their effect upon the stabilization of the foam is given later.

The presence of solid particles in a slag has been considered as a possible cause of the formation of a froth. Solids are known to increase the stability of aqueous froths in some cases. It is likely that in multi-component slags there may be present a third disperse phase, either solid or liquid, which may help to stabilize any foams which are formed. Davis[15] has suggested this possibility, pointing out that the introduction of a suspension into the slag would increase its viscosity. He has further suggested that the addition of lime to a slag may liberate iron and manganese as crystalline oxide phases and also that during a considerable period of the heat much of the lime is not in solution. Crystallization of Ca_2SiO_4 from the slag was proposed by Davis as a third source of solid material in the slag. Some experiments described by Davis were carried out to test this idea. Additions of Ca_2SiO_4 were made to a slag in order to see if foaming could be induced. It was found that on adding ore to slag and molten iron held in a graphite crucible, foaming could be induced provided the slag contained Ca_2SiO_4. The Ca_2SiO_4 (1–3%) was added to the slag as a fine powder about 5 min before the ore addition. As a graphite crucible was used the iron presumably contained nearly 5% carbon. The foam persisted for 5 min or more. However, a second ore addition produced no durable foam. Presumably the Ca_2SiO_4 had dissolved by the time the second addition was made.

Furnace atmosphere and foaming

The type of gaseous fuel used to heat the melt and also the luminosity of the flame it produces are reported to have a marked effect upon the foaming of slags. Evans[9] has discussed the luminosity of the heating flame and defined an 'actual' and an 'apparent' luminosity. He stated that although a flame may appear 'dazzling white', a foam may still occur if too much iron is present in the slag. In this case, he said, it is the apparent luminosity which is observed, and he later suggested that the ability of the actual luminous flame to destroy a foam was due to its penetrative heat. It is difficult to follow Evans's argument although the evidence does suggest that the luminosity of the flame has some effect on foam formation. The luminosity is apparently a function of the amount of carbon in the flame and the degree to which it is dispersed. Kozakevitch[16] suggested that the carbon particles are able to destroy a foam by forming secondary CO_2 bubbles in the foam films, the CO_2 arising from the reduction of oxides in the films. If secondary bubbles are formed it is debatable whether they will cause bubble rupture or



1 Jet and thermocouple; 2 Observation window; 3 water-cooled furnace case; 4 Contact cone for element; 5 Radiation shields; 6 Element; 7 Crucible; 8 Pedestal; 9 Inlet for N_2–H_2 mixture.

1 *Diagram of apparatus used for measuring foam stability*

whether they will contribute to the froth, but it is possible that the carbon alters the composition of the surface layer of the bubble lamellae to such an extent that it becomes unstable.

Several other observations of the effect of furnace atmosphere upon foaming have been reported in the literature. It is said that foams seldom arise with furnaces fired with producer gas[9,17] or furnaces fired with coke-oven gas provided atomized pitch or tar is included to the extent of one-third of the total heat input.[9] Radtke[17] has stated that foams are more prevalent with oil-fired furnaces and attributed this to the fact that they are usually run with a large excess of air, causing a high rate of oxidation. Philbrook,[18] however, believed that an oil flame, being a hot flame, alters the slag composition rapidly and thus gets it past the critical foaming range quickly.

It seems impossible to draw any definite conclusions, from the information available, as to the nature of the effect of gas atmosphere upon the foam stability; some gases may have a foam-breaking or inhibiting action rather than any direct action as foaming agents.

Influence of melt conditions upon foaming

A factor which may be of great importance in the formation of slag foams has been pointed out by Larsen.[19] This is the nature of the boil which occurs during the refining period. If the melt is quiet, i.e. very little stirring action takes place within the metal bath, it is possible that the slag may become sufficiently oxidizing for bubbles to form at the slag/metal interface. These bubbles will in all probability be far smaller than those which reach the slag during a normal boil, when the oxidation reaction occurs at the hearth bottom under 2–4 ft of molten steel. With liquids having viscosities of the same order of magnitude as that of slags, it is possible to form dispersions of fine bubbles in the liquid which are stable for relatively long periods. Thus, if fine bubbles are formed at the slag/metal interface a dispersion may be formed and may persist until the normal boil has begun. Sims,[20] however, considered that if a surface boil does start it will not be confined to the surface for long.

Conclusions from previous work

It is clear from the sparse information briefly mentioned above that the foaming of slags in steelmaking plant is influenced by many factors and that scattered industrial observations are inadequate to elucidate the phenomenon. In particular, controlled laboratory experiments are needed to settle the question whether true foams, dependent on surface-chemical factors, are involved.

EXPERIMENTAL

Measurement of the foam stability of synthetic slags

Methods for quantitative measurements on foams are designed with the object of assessing the foaming ability or foam stability of a liquid. Because foaming is not a standard physical property of a liquid in the same sense as boiling point, viscosity, or density, the process of quantitative measurement is arbitrary and results obtained depend upon the apparatus used. Essentially two types of measurement are commonly made, the measurement of the stability of single bubbles or films and the measurement of the stability of a foam produced under standard conditions. Following certain preliminary experiments (carried out for convenience with liquid paraffin and aqueous glycerol solutions) it was decided to adopt the latter type of measurement for a study of silicate foams, the chief reason being that observations on single bubbles or films are very subject to effects of contamination and are often not reliable measures of dynamic foaming.

The apparatus used permitted the life of a given volume of foam to be determined. Since foam stability depends on bubble size, all measurements were made at roughly constant bubble size. The apparatus is shown diagrammatically in Fig.1. A molybdenum jet was introduced into about 20 g of melt contained in a molybdenum crucible 1 in. dia. and 3 in. tall. On the side of the crucible were mounted two molybdenum pointers, one $1\frac{5}{8}$ in. above the other, and $\frac{3}{8}$ in. from the top of the crucible. The bottom pointer normally rested $\frac{3}{16}$–$\frac{1}{4}$ in. above the melt surface.

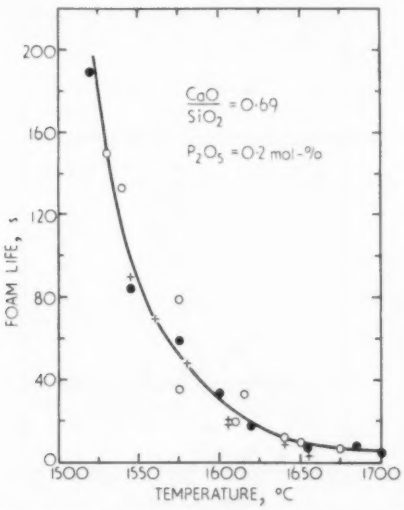
It was necessary to fabricate the jet from molybdenum sheet, since refractory tubes capable of withstanding temperatures up to 1750°C in contact with siliceous melts in a reducing atmosphere were not available. It was found that to produce bubbles of 5 mm dia. with a jet made from a wide-bore tube ($\frac{1}{8}$ in.) an extremely fine orifice was required, i.e. 0·005–0·01 in. dia. Jets of this type were fabricated from molybdenum sheet but were too easily blocked. This difficulty was overcome by constructing a flat-bored molybdenum capillary tube with a large orifice at its tip. This type of jet permitted bubbles to form slowly in melts and rise from the hole by buoyancy before a large volume of gas had been introduced into them. The jet was constructed by welding together at the edges two strips of 0·01-in. molybdenum sheet 10 in.

long and $\frac{1}{4}$ in. wide. At a distance of about $\frac{1}{4}$ in. from the end of one strip a hole $\frac{1}{16}$ in. dia. had been drilled to serve as the jet. The construction was completed by welding together the ends of the strips below the orifice. It was found that by having 5–6 in. of the jet with the strips welding close together, a sufficient restriction of gas flow was caused, so the remainder of the jet was made with one strip slightly bowed along its longitudinal axis to permit free passage of gas.

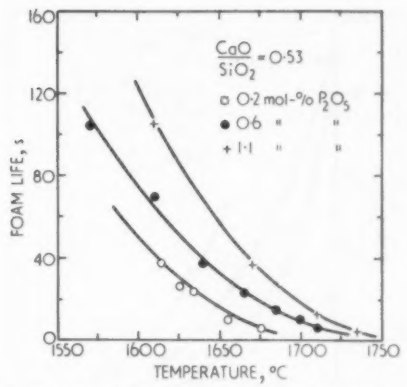
The crucible, constructed by welding from molybdenum sheet,[21] was heated in a molybdenum tube furnace[22] and could be observed from above through a mica window in the top of the furnace.

The melts were made up by weight from 'Analar' $CaCO_3$, 'BP' $Ca_3(PO_4)_2$, and acid-washed crushed mineral quartz.

In the measurements, gas was forced through the jet at a pressure sufficient to form bubbles of about 5 mm dia. (4–5 lb/in^2). The size of the bubbles was estimated by counting the number of bubbles which spanned the crucible. A foam was then built up to the top pointer and, after releasing the excess pressure in the jet, the time for the foam to decay to the bottom pointer was recorded. At high temperatures, where the foam life was very short (a few seconds), foams could not be built up to the top bar: in these cases the foam was built up to its maximum height and the time for decay to the bottom pointer recorded. With the more stable foams (foam life greater than 1–1$\frac{1}{2}$ min) the breakdown of the foam often gave rise to large films which spanned the crucible. This made it difficult to assess the time at which the bottom pointer appeared. In these circumstances the time was noted when only films spanning the crucible, or two or three films joined in the crucible forming a 'foam' of a few very large bubbles, remained above the pointer. The times recorded in this way were generally similar to those obtained from a foam which decayed normally. The formation of the large films limited the range in which measurements could be made, since if the foam life was greater than about 2 min its determination was very uncertain.



2 *Graph of foam life against temperature for three melts of the same composition*



3 *Graph of foam life against temperature for acid melts of* $CaO/SiO_2 = 0{\cdot}53$

It is noteworthy that the films mentioned above showed what appeared to be interference colours which changed rapidly in a similar manner to those observed with many aqueous films. A further similarity to aqueous foams was the fact that the last remaining bubbles, those in contact with the crucible wall and the underlying melt, were exceptionally stable.

In most cases the determination of the foam life was carried out ten or more times at a particular temperature and a mean value calculated. Standard deviations on the times were ± 10–15%.

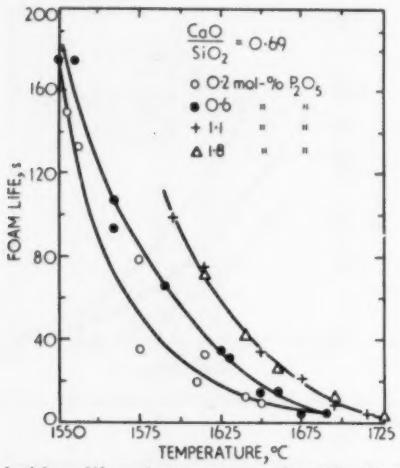
Temperatures were measured with tungsten/molybdenum thermocouples held in a molybdenum thermocouple sheath, mounted alongside the jet with the tip in the melt. These thermocouples needed annealing and careful calibration and handling. An absolute accuracy of about ± 5°C could be obtained and provided one couple was used for a given run it was considered that any error would be constant. However, an average temperature gradient of 15–20°C existed above the melt in the crucible owing to the lack of radiation shields above it. This was not considered a serious drawback since all measurements were comparative and made under essentially identical conditions. One advantage of the temperature gradient was that it gave greater visibility of the foam.

In all the measurements made, a mixture of $10\%H_2$ and $90\%N_2$ gas was passed through the furnace and used to blow the bubbles. It is important to bear this in mind since industrial observations have shown that the nature of the gas atmosphere sometimes affects the stability of slag foams.

Results

CaO–SiO_2 melts were used throughout the experiments to represent refining slags. In the pure state they are practically free from foaming (*see* Figs. 2–10). Kozakevitch[16] has suggested that P_2O_5 may be operative in slag foam stabilization; preliminary experiments showed that additions of P_2O_5 as $Ca_3(PO_4)_2$ to CaO–SiO_2 melts did give some increase of foam stability. This system was therefore investigated for variation of foam stability with composition and temperature.

The results obtained are shown in Figs.2–8. Figure 2 shows the reproducibility of the measurement as indicated by the results obtained with three



4 *Graph of foam life against temperature for acid melts of* $CaO/SiO_2 = 0{\cdot}69$

different melts of the same composition. Figures 3–5 show the results obtained with acid melts where foaming was most pronounced. In Fig.6 is shown the maximum foaming obtained with neutral or basic melts where the foam life was small and variable. Figures 7 and 8 illustrate the variation of foaming with $CaO : SiO_2$ ratio with constant P_2O_5 content.

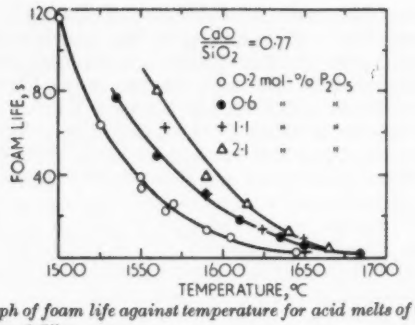
Melts free of P_2O_5 either foamed slightly or not at all: experiments were started with a melt which had been checked and found to have negligible foaming ability, the $Ca_3(PO_4)_2$ being added later, together with some SiO_2 to keep the $CaO : SiO_2$ ratio constant. In melts with a $CaO : SiO_2$ ratio (molar) greater than about 1 : 1 the P_2O_5 additions had little or no effect upon the foaming. With $CaO : SiO_2$ ratios less than 1 : 1 the foaming increased with P_2O_5 content to about 1 mol-%. The foaming also increased markedly with fall of temperature and with decrease in the $CaO : SiO_2$ ratio. Measurements at high silica content had to be made quickly as it was found that the P_2O_5 distilled out and condensed on the cooler parts of the furnace, presumably as phosphoric acid. Additions of $(NH_4)_2MoO_4$ to a melt were found to have no effect upon its foam stability, ruling out the possibility of any influence upon the foaming of contamination of the melt by the crucible material.

A graph of $\log_{10}$ (foam time) against $1/T$ (°K) gives in most cases an approximate straight line (Fig. 9), the slope of which is about four times as great as a similar graph of $\log_{10}$ (viscosity) against $1/T$ (°K). This indicates that the foam life does not have a direct dependence upon bulk viscosity: in non-stabilized dispersions of bubbles in viscous liquids, the temperature coefficient of the persistence gives the same activation energy as for viscous flow of the liquid.[29]

The measurement of the surface tension of the foaming slags

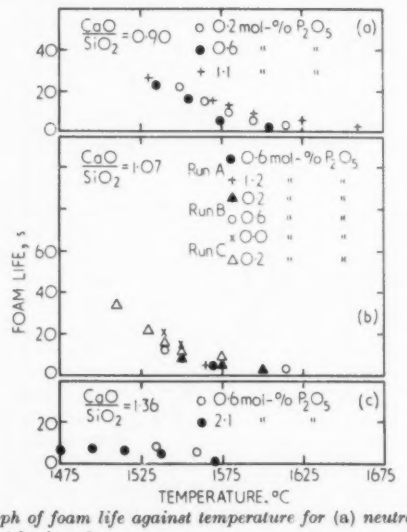
As P_2O_5 was found to act as a foaming agent it was expected to be surface active; measurements were therefore made to investigate the surface tension lowering when P_2O_5 was added to $CaO–SiO_2$ melts.

Initially attempts were made to use a method similar to that used by Harrison and Moore[23] in which the pull on a hollow cylinder located at the surface of

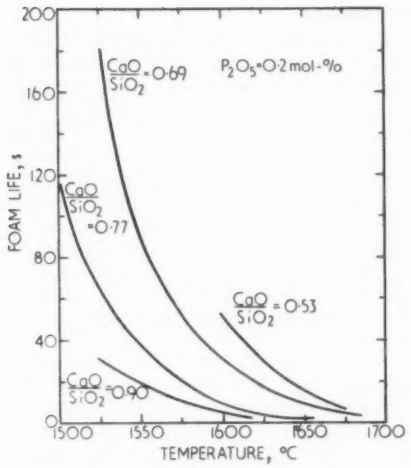


5 *Graph of foam life against temperature for acid melts of* $CaO/SiO_2 = 0{\cdot}77$

a melt permits the surface tension to be determined. However, it was found that P_2O_5 introduced an angle of contact between the melt and the molybdenum cylinder. It was therefore necessary to use a method independent of contact angle, namely the maximum bubble pressure method. Parmelee *et al.*[24] have already used this method for determining the surface tension of silicate melts. The apparatus used here was similar to that used by Parmelee except that the jet had to be made by drilling molybdenum rod. Because of the size of the furnace, the jet needed to be over 30 cm long and, in order that the maximum pressure could be easily determined with sufficient accuracy, it was necessary for the jet diameter to be 1–2 mm. The jet was therefore built from two shorter lengths of tube as follows: a $\frac{1}{4}$-in. dia. molybdenum rod, 6 in. long, was drilled with an $\frac{1}{8}$-in. dia. drill to within about $\frac{1}{4}$ in. of one end, i.e. to a depth of $5\frac{3}{4}$ in. A smaller drill (1–2 mm dia.) was passed through the remaining $\frac{1}{4}$ in. to form the hole at which the bubbles were to be blown. The molybdenum tube was then fitted into a $\frac{1}{4}$-in. bore mild-steel tube so that the tubes overlapped by about 1 in. and the end of the steel tube was welded around the molybdenum. To complete the jet a tapered broach had to be used inside the jet to ensure that the hole at the tip was the smallest diameter within the jet. This was necessary since it was found that in



6 *Graph of foam life against temperature for* (a) *neutral and,* (b, c) *basic melts*



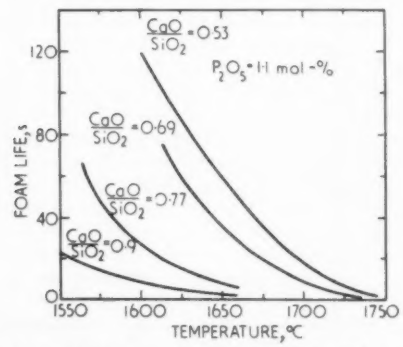
7 *Variation of foam stability with* $CaO : SiO_2$ *ratio and constant* P_2O_5 *content (0·2 mol-%)*

drilling the small hole the drill tended to wander, because of the hardness of the molybdenum, resulting in an irregular and tapered bore which gave rise to spurious results in preliminary experiments.

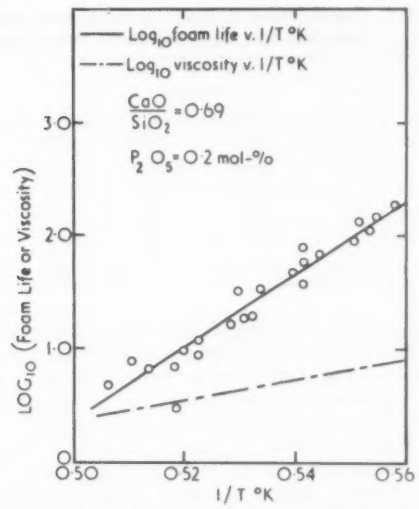
Measurements were made in a similar way to that described by Parmelee except that a slow continuous flow of gas was passed into a reservoir attached to the jet. Provided each bubble took about 4 min to form the true maximum pressure was recorded.

Results

In almost all the measurements made a small drift of surface tension with time was observed, the surface tension increasing by about 2–5 dyn/cm h. Attempts to eliminate the drift or discover its cause were unsuccessful. It is noteworthy that King[11] observed 'hysteresis' of surface tension with several silicate melts; i.e. if measurements were made at a certain temperature, and then the melt heated further, on cooling it to the original temperature a higher surface tension was obtained. It was not stated whether on maintaining the melt at a constant temperature the surface tension returned to its original value. It is possible that the hysteresis was in fact a drift since in this work it was observed that on holding the melt at a



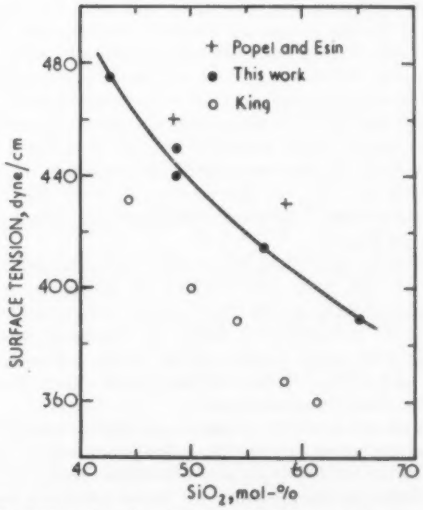
8 *Variation of foam stability with* $CaO : SiO_2$ *ratio at constant* P_2O_5 *content (1·1 mol-%)*



9 *Log graph of foam life and viscosity against the inverse of the absolute temperature*

constant temperature no reversal of drift could be obtained. Because of the uncertainty regarding the true cause of the drift and also its erratic nature no attempt was made to correct the values for the surface tensions obtained but a mean was calculated of all the results obtained with a given melt. Results obtained in this way have a random error of about $\pm 1\%$ but it is probable that the absolute value of the surface tension is 1–2% lower than the mean value. Further, since the same jet was used throughout a run, starting with pure $CaO–SiO_2$ melts, to which successive additions of P_2O_5 were made, the true surface tension lowerings due to P_2O_5 may be slightly larger than those recorded but fortunately the uncertainty is unimportant to the present investigation.

The results obtained for the $CaO–SiO_2$ system are shown in Fig.10, together with the results of King,[11] and Popel and Esin,[25] which are respectively lower



10 *Variation of surface tension with* SiO_2 *content*

TABLE I The influence of P_2O_5 on the surface tension of pure CaO–SiO_2 melts of various molar ratios

CaO/SiO_2, moles	CaO, wt-%	Surface tension, dyn/cm			
		P_2O_5 added, mol-%			
		Nil	0·4	1·1	1·8
0·54	33·5	389	387	378	—
0·77	41·8	415	410	403	396
1·06	49·7	440	447	431	415
		450	439	415	404
1·35	55·7	475	—	—	—
		475	470	—	—
		475	475	467	447
		477	471	454	437

1 mol-% P_2O_5 corresponds to about 2·5 wt-%

and higher than the results obtained in this investigation. The difference may be due to inaccuracies in one or more of the methods used or to differences in gas atmospheres or trace impurities.

The effect of P_2O_5 on the surface tension of CaO–SiO_2 melts is shown in Table I. It can be seen that P_2O_5 lowers the surface tension of the melts and is more effective per mole than $2SiO_2$ in doing so. Further, the surface tension lowering is greater in basic than in acid melts.

Because of the drift of surface tension with time, it was not possible to make a precise study of the temperature coefficient of surface tension of the melts used. It was concluded, however, that the temperature coefficient must be small. In the case of the melt containing 65 mol-% SiO_2 it was possible to estimate the temperature coefficient since there was least drift with this melt. It was found that the coefficient was positive and of the order of 0·05 dyn/cm °C. King[11] obtained a coefficient of +0·07 dyn/cm °C with a melt containing 61 mol-% SiO_2.

The surface concentration of SiO_2 in CaO–SiO_2 melts

The surface concentration of SiO_2 has been calculated by means of the Gibbs adsorption equation from the surface tension data obtained for the CaO–SiO_2 system. For this calculation the components were taken as CaO and SiO_2 and the values for the activity of SiO_2 in CaO–SiO_2 melts estimated by Richardson[26] were adopted. The method used to calculate the surface concentrations was that outlined by Guggenheim.[27] It was necessary to make an estimate of the areas occupied by one molecule of CaO and SiO_2 in the surface: as a first approximation these were calculated from known crystallographic data and found to be 11·0 Å² and 12·3 Å² respectively, but to simplify the calculation a mean value of 11·7 Å² was used. From the surface excess concentrations obtained, the mole fractions of SiO_2 in the surface of CaO–SiO_2 melts were calculated. The results obtained are shown graphically in Fig.11.

It can be seen that in a melt containing 60 mol-% SiO_2 in the bulk the surface is composed almost entirely of SiO_2; at 50 mol-% SiO_2, two-thirds of the surface is occupied by SiO_2. As viscosity increases steeply with silica content in the range between CaO–SiO_2 and SiO_2,[13,14] the surface layer must be more viscous than the bulk liquid.

It was not possible to carry out similar calculations of the composition of the adsorption layer on the ternary CaO–SiO_2–P_2O_5 melts because thermodynamic data (activity coefficients) for these solutions are not available.

Surface viscosity

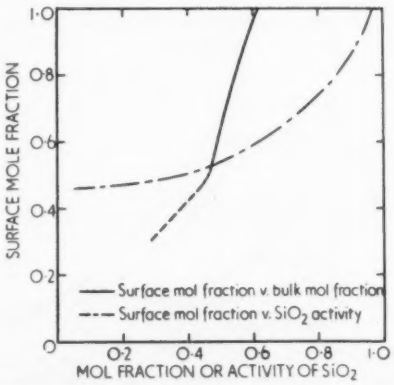
Attempts were made to determine the effect, if any, of P_2O_5 upon the surface viscosity of the CaO–SiO_2 melts, since many aqueous solutions which give rise to stable foams have a high surface viscosity. The torsion pendulum technique as described by Harkins and Meyers[28] was adopted for the measurements. Instead of a ring, a hollow cylinder was used of about 1·5 cm dia. and the melt was contained in a crucible of 1·7 in. dia. However, owing to the experimental difficulties of making such measurements at high temperatures, the sensitivity was too low to detect any but large changes of surface viscosity. No difference was observed when P_2O_5 was introduced into the CaO-SiO_2 melts.

DISCUSSION

The present measurements have confirmed the industrial observation that for a CaO–SiO_2 melt to foam it must be acid. However, it has been shown that in a reducing atmosphere acidity alone is insufficient for foaming to occur, since melts containing up to 65 mol-% (67 wt-%) SiO_2 did not foam appreciably in the absence of P_2O_5. This indicates that the foams obtained in steel refining are not primarily viscosity-dependent, although no doubt with a melt of sufficiently high viscosity and with bubbles of very small size a temporary dispersion could occur with a relatively long life.

Causes of the foam stabilization

In a recent critical review[29] of the theory of foaming, the present authors have shown that although several contributory factors affect foaming, the essential factor for true foaming is the property of surface elasticity. Strong surface elasticity arises only with dilute solutions of surface-active solutes and is due partly to depletion of the solute concentration in the thin lamella by Gibbs adsorption and partly to the difference between dynamic and static surface tensions (the Marangoni effect). The CaO–SiO_2 melts used can be regarded as solvents to which the addition of a surface-active material, e.g. P_2O_5, is necessary in order to produce a foam. P_2O_5 can be treated as a dilute surface-active agent, since it lowers the surface tension of CaO–SiO_2 melts more than does an equivalent molar quantity of SiO_2, which, in any case, is present in excess.



11 *Surface concentration of* SiO_2

The persistence of any foams produced should be dependent partly on bulk and surface viscosity. In agreement with expectation, in all the ternary mixtures foam life was found to increase greatly with increase of bulk viscosity, whether this was brought about by fall of temperature or by decrease in the CaO/SiO_2 ratio.

It would be an over-simplification to postulate any simple relation between foam life and viscosity or even to expect systems of equal viscosity to have the same foam life, though this is approximately true for the foams in the melts of $CaO/SiO_2 = 0{\cdot}90$, 0·69, and 0·53 (54–67 wt-% SiO_2). For example, rise of temperature not only accelerates the drainage of lamellae, but also reduces the strength of surface elasticity by accelerating diffusion of the surface-active component to the surface and hence diminishing the magnitude of the Marangoni effect. It is not surprising, therefore, that the temperature coefficient for the rate of collapse of the foams is considerably greater than the temperature coefficient of fluidity (Fig.9). Nevertheless, as increase of viscosity always favours foaming in this, as in other systems, it seems probable that viscosity is an important factor here.

Structure of the adsorption layer

Although, from a thermodynamic point of view, the components can legitimately be treated as CaO, SiO_2, and P_2O_5, it is not implied that these molecular structures are present as such. The probable structures of the silicate ions in the melt have been discussed elsewhere.[14] The P_2O_5 probably enters the melt as PO_4 tetrahedra, differing only from SiO_4 tetrahedra in their charge, and, hence, probably a series of silicophosphate structures analogous to the discrete silicate ions can exist. Following Kozakevitch,[15] it is reasonable to suppose that an adsorbed silica layer would link up into rings. They would be disordered, as in vitreous silica, with 5, 6, or 7 members and, of course, non-planar. Each SiO_4 would have one Si–O bond directed towards the bulk phase. Adsorbed phosphate might consist of similarly situated PO_4 tetrahedra, but having a doubly-bonded oxygen atom below instead of a network-forming bond on to the substrate.

Practical implications

These results suggest that foaming of steelmaking slags probably arises chiefly with acid slags containing surface-active impurities such as P_2O_5. (B_2O_3 and to a lesser degree, Al_2O_3 were found to act in the same way, but TiO_2 was ineffective.) Severity of foaming would be enhanced by a low temperature or other factors making for high viscosity, together with conditions favouring the evolution of small bubbles of gas. A high-lime environment and high temperature should therefore be favourable for avoiding foaming.

These conclusions, however, do not take account of the possible effects of $FeO–Fe_2O_3$ in practical slags, the laboratory experiments having been carried out in a reducing atmosphere, in the absence of iron. It is hoped to ascertain the effect of these factors by further work now in progress.

CONCLUSIONS

(1) Pure $CaO–SiO_2$ melts do not foam appreciably.

(2) Marked foaming is obtained with $CaO–SiO_2$ slags containing more than 67 wt-% SiO_2 when 1–2 wt-% P_2O_5 is added. The foaming is stronger the lower the $CaO : SiO_2$ ratio, the greater the $\%P_2O_5$, and the lower the temperature.

(3) Surface tension measurements show that P_2O_5 is adsorbed at the surface. The foaming is probably due to surface elasticity, the persistence of the foams being increased by conditions favouring high melt viscosity.

(4) These experiments do not take into account the possible effect of $FeO–Fe_2O_3$ in practical slags.

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REFERENCES

1. K. Fellcht: *Metallurgie u. Giesserei Technik*, 1955, **5** (3), 85–98.
2. F. Franz: *ibid.*, 101–102.
3. 'Basic open-hearth steelmaking', 180: 1944, New York, AIME
4. F. Keil: *Stahl Eisen*, 1942, **62,** 1091.
5. K.-F. Ludemann: *Metallurgie u. Giesserei Technik*, 1955, **5** (3), 101.
6. P. Kozakevitch: *Rev. Mét.*, 1949, **46,** 572–582.
7. W. Woytt: *Metallurgie u. Giesserei Technik*, 1955, **5** (3), 101.
8. K. G. Speith and H. Heinrichs: *Rev. Univ. Min.*, 1953, **96,** 541–545.
9. R. W. Evans: *Blast Furn. Steel Plant*, 1944, **32,** 932–935.
10. P. Kozakevitch: *loc. cit.*, 505–516.
11. T. B. King: *Journal of the Royal Technical College, Glasgow*, 1950, **5,** 217–225; *J. Soc. Glass Techn.*, 1951, **35,** 241–259.
12. 'Introduction to the physical chemistry of steelmaking,' 370: 1945, BISRA.
13. J. O'M. Bockris and D. C. Lowe: *Proc. Roy. Soc.*, 1954 (A), **226,** 423–435.
14. J. O'M. Bockris, J. A. Kitchener, and J. D. Mackenzie: *Trans. Farad. Soc.*, 1955, **51,** 1734–1748.
15. H. M. Davis: *AIME Proc. OH Conf.*, 1949, **32,** 238–240.
16. P. Kozakevitch: *J. Chim. Phys.*, 1950, **47,** 24–32.
17. R. Radtke: *Metallurgie u. Giesserei Technik*, 1955, **5** (3), 102.
18. W. O. Philbrook: *AIME Proc. OH Conf.*, 1949, **32,** 234–235.
19. B. M. Larsen: *ibid.*, 231–233.
20. C. E. Sims: *ibid.*, 236–237.
21. J. W. Tomlinson *et al.*: *J. Sci. Inst.*, 1954, **31,** 107–108.
22. J. O'M. Bockris, J. A. Kitchener, and A. E. Davies: *Trans. Farad. Soc.*, 1952, **48,** 536–548.
23. W. N. Harrison and D. G. Moore: *J. Res. NBS*, 1938, **21,** 337–346.
24. A. E. Badger, C. W. Parmelee, and A. E. Williams: *J. Am. Ceram. Soc.*, 1937, **20,** 325–329.
    C. W. Parmelee and C. G. Harman: *ibid.*, 224–230.
    C. W. Parmelee and K. C. Lyon: *J. Soc. Glass Techn.*, 1937, **21,** 44–52.
25. S. I. Popel and O. A. Esin: *Zhurnal Neorganicheskoi Khimii*, 1957, **2,** 632–641.
26. F. D. Richardson: 'The physical chemistry of melts,' 83: 1953, London, Institution of Mining and Metallurgy.
27. A. E. Guggenheim: 'Thermodynamics,' 217: 1949, North Holland Publishing Company.
28. W. D. Harkins and R. J. Myers: *Nature*, 1937, **140,** 465; *J. Chem. Phys.*, 1937, **5,** 601–603.
29. J. A. Kitchener and C. F. Cooper: *Quarterly Reviews of the Chemical Society*, 1959, **13,** 71–97.

The effect of specimen size on tensile properties of coarse-grained medium-carbon steel at low temperatures

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SYNOPSIS

Tensile tests at temperatures between 20° and −196°C were carried out on an annealed 0·43%C steel, using geometrically similar test pieces of various sizes from 0·01 to 0·33 in², to determine size effects.

Ductility showed a considerable size effect which varied with temperature and attained a maximum at or just below −120°C. Generally, by decreasing the size of the test piece the temperature range was lowered within which any given decrease in ductility occurred. No appreciable size effect was observed in yield point but ultimate stress values increased with decreasing size of test piece at −196°C.

Tensile fracture appearance was very sensitive to size and was related to the volume of the cylindrical part of the test piece rather than the area, suggesting that the total stored elastic energy before fracture was a factor in determining the type of fracture and degree of embrittlement exhibited. 1611

THIS INVESTIGATION was undertaken to determine whether at low temperatures, in plain round bar tensile tests, any specimen size effects were produced which contrasted with those observed at room temperature, since in another investigation it was found that at a test temperature of −196°C the smaller of two test pieces gave the greater elongation value.

Size effect has previously been investigated chiefly at room temperature in mild and similar types of steel, particularly in ship-plate material. The tests were frequently designed to reproduce some special service condition in which notches were involved. Notched specimens have been used in round and flat tensile tests as well as in standard impact tests. Size effects have also been investigated in torsion and bend tests.

In the few results for plain round tensile tests there has been some disagreement by previous investigators. Thus, although it has generally been found that the UTS increased with decrease in bar diameter, ductility values have shown less consistent behaviour. Miklowitz[1] reported that elongation and reduction in area values increased as the specimen size decreased, while Duwez, Wood, and Clark[2] found, in impact tensile tests, that both elongation and reduction in area decreased with decrease in size. Lyse and Keyser[3] reported that elongation decreased and reduction in area remained constant with decrease in diameter of test piece, but Shearin, Ruark, and Trimble[4] found that reduction in area increased with decrease in size and were thus in agreement with Miklowitz. Parker[5] concluded that there was no appreciable size effect with plain round specimens at room temperature.

A size effect at temperatures other than room temperature was recorded by Davidenkov, Shevandin, and Wittmann,[6] who showed that in tensile tests the ductile-to-brittle fracture transition temperature decreased with decrease in specimen diameter. They found no appreciable variation in reduction in area values.

COMPOSITION AND HEAT-TREATMENT OF MATERIAL

The percentage analysis of the steel, En8-V4A/2, used in this investigation was as follows:

C	Si	Mn	S	P	Ni	Cr
0·43	0·13	0·65	0·028	0·028	0·03	0·03

The material was annealed at 900°C to develop a large grain size conducive to the production of brittle fractures at low test temperatures. The mixed grain size obtained was composed of about 70% ASTM 3 and 30% ASTM 6.

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APPARATUS, TEST PIECES, AND EXPERIMENTAL TECHNIQUES

Tensile testing was carried out on a Losenhausen hydraulic machine of 35 tons capacity with a pendulum load-measuring system. Gauge plates were fitted to the specimens, 2 in. apart, and these were used to actuate Baldwin microformer strain gauges through suitable mechanical linkages. The strain gauges were connected with high magnification (×500) and low magnification (×25) load-extension recorders, the former being switched off after the yield point had been recorded, while the latter was operative throughout each test up to fracture. The load-measuring sections of the recorders consisted of Bourdon tubes connected to the hydraulic circuit of the testing machine and these were calibrated against the Losenhausen load dial. The low magnification recorder was also used to drive a strain-pacer which permitted manual control of the rate of strain at about 0·04 in./in./min throughout the test. The strain rate was thus kept constant at least up to that strain where 'necking' began. Apart from the type of extensometer used, the general arrangement of the apparatus was similar to that described by Hall and Nichols.[7]

The tests at sub-zero temperatures were carried out with the specimens completely immersed at all times in a suitable coolant which was circulated by a

centrifugal pump. For tests at −50°C the circulating liquid used was ethyl alcohol, chilled in an external chamber by the direct addition of solid carbon dioxide. For temperatures of −100° and −120°C the fluid used was commercial pentane which was cooled in an external chamber containing a hollow copper coil through which liquid nitrogen was passed. Both liquids were cooled to below the required testing temperature and were pumped into a bath containing an annular electric heater, and then into the testing bath surrounding the specimen. A pipe from the bottom of the test bath allowed the coolant to pass back into the cooling chamber, the flow being regulated so that the level of the coolant in the test bath remained reasonably constant. The temperature of the liquid in the test bath was measured by a resistance thermometer and controlled by a potentiometric recorder which governed the on–off period of the electric current passing through the annular heater. Tests at −196°C were carried out by filling the testing bath with liquid nitrogen, and to maintain a constant level of liquified gas in the bath the method and electronic controller described by Hall and Nichols[7] were used.

The test pieces used in the investigation were of eight different cross-sectional areas varying from 0·01 to 0·33 in². The test pieces were made geometrically similar with a parallel length of $5\sqrt{\text{area}}$, and two further sets of specimens were made relatively longer, one 0·0625 in² had a parallel length of $13{\cdot}25\sqrt{\text{area}}$, and the other, 0·125 in², a length of $8{\cdot}5\sqrt{\text{area}}$. All tests were carried out in duplicate.

The two smallest sets of test pieces with areas of 0·01 and 0·025 in² were broken in a Hounsfield tensometer, the load calibration of which was checked against the 35-ton machine. The tensometer was motor driven and gave a straining rate of about 0·03 in./in./min. It was mounted vertically with the test pieces completely immersed in a liquid cooling bath throughout the duration of the test. A special extension grip was used so that the testing bath was sufficiently remote from the spring beam of the tensometer to have no cooling effect upon it. The methods of cooling, maintenance of the level of the coolant in the testing bath, and temperature measurement and control were as described for the larger test pieces.

Measurements of elongation and reduction in area were made when the test pieces had regained room temperature. The elongation values were always measured on the standard gauge length of $4\sqrt{\text{area}}$. The dimensions of the test pieces are given in Table I.

TABLE I Dimensions of test pieces

Code	Cross-sectional area, in² Nominal	Actual	Dia., ±0·0005 in.	Parallel length, in.	Ratio to √area	Overall length, in.	Volume of cylindrical portion, in³
A	0·010	0·010	0·113	0·50	5·00	1·32	0·004
B	0·025	0·025	0·1785	0·79	5·00	1·60	0·016
*C	0·0625	0·062*	0·280*	1·25	5·09	3·00	0·078
D	0·0625	0·062	0·280	3·25	13·24	5·25	0·203
E	0·100	0·098	0·354	1·60	5·06	4·25	0·160
F	0·125	0·123	0·3955	1·75	4·99	4·75	0·219
G	0·125	0·123	0·3955	3·00	8·49	6·00	0·375
H	0·200	0·197	0·502	2·25	5·03	5·00	0·450
J	0·250	0·246	0·560	2·50	5·00	5·50	0·625
K	0·33	0·326	0·643	2·90	5·02	6·00	0·967

* The tensile machine in which specimens C–K were tested was calibrated in metric tons (1 British ton = 1·016 metric tons). To read stresses in British tons/in², cross-sectional areas were reduced in the correct proportion. Nominal cross-sectional areas are also given.

EXPERIMENTAL RESULTS

Measurements of the elongation and percentage reduction in area of the upper and lower yield points and of UTS were made at test temperatures of +20°, −50°, −100°, −120°, and −196°C. The variation of tensile properties with temperature and with specimen size are given in Tables II and III.

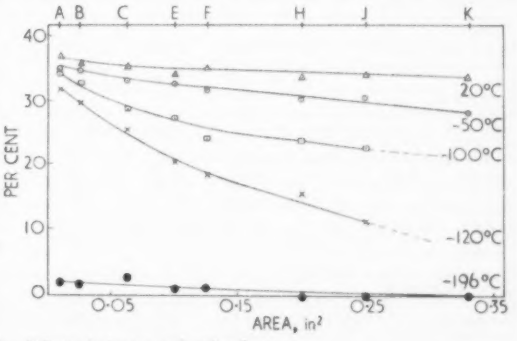
The general characteristics of the relative effect of different test temperatures on the measured properties were normal for this type of steel, and were similar for each size of test piece, i.e. ultimate stress and yield point were subject to a continuous increase with decrease in temperature; reduction in area showed a continuous decrease which was very slight immediately below room temperature but became very marked below −100°C; elongation generally showed a slight increase down to −50°C, exceptions to this being among the smaller specimens, but with further decrease in temperature there was a continuous decrease of elongation in conformity with the variation of the reduction in area.

To indicate graphically whether size effect occurred and, if so, how it was affected by temperature, the test results have been plotted with the sizes of the specimens as abscissae. The curves, Figs.1–3, show the variation under uniform temperature conditions at various levels for geometrically similar test pieces. They indicate that reduction in area values generally increased as the test piece size was reduced, for all test temperatures, whereas elongation values were not affected significantly until a temperature of −100°C was reached. In both cases the maximum effect occurred at −120°C. Test pieces A, B, and C showed the tensile strength to increase with reduction in specimen diameter at −196°C, but no effect was observed at higher temperatures. Upper and lower yield points showed no size effect down to −120°C, and were not present at the lowest test temperature used.

The type of fracture showed a considerable size effect at room temperature, the larger test pieces showing smaller amounts of fibrous fracture than the smaller specimens. This effect was also present at −50°C although to a lesser extent, but at lower temperatures the tensile fractures tended to become wholly crystalline.

DISCUSSION

Size effect is defined as a variation in the mechanical



1 *Effect of size on reduction in area*

TABLE II Tensile test results, sizes up to 0·10 in²

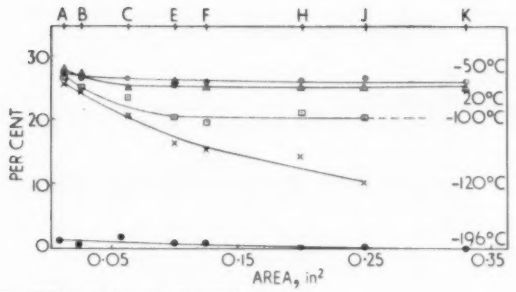
Test piece size		A		B		C		D		E	
+20°C											
Upper yield point	tons/in²	...	...	17·2	18·5	17·4	17·2	17·3	16·8	17·0	16·3
Lower yield point	„ „	16·5	16·8	16·2	17·0	17·2	16·5	16·4	16·0	16·5	16·0
UTS	„ „	37·6	37·5	37·7	37·6	37·1	36·8	36·5	37·1	36·7	37·0
Elongation	%	28·0	28·0	26·5	27·6	25·0	25·0	28·0	28·0	26·4	25·6
Reduction in area	%	36·0	38·0	35·0	37·0	35·2	35·8	35·2	36·3	35·3	34·0
−50°C											
Upper yield point	tons/in²	...	...	20·6	21·2	20·3	20·9	20·2	20·2	20·0	20·7
Lower yield point	„ „	22·1	21·3	20·1	20·7	19·6	20·0	19·5	19·5	19·7	20·0
UTS	„ „	43·0	42·2	41·2	42·0	40·5	40·6	41·1	40·5	40·7	41·2
Elongation	%	27·0	28·0	26·0	27·2	27·0	26·0	28·0	28·0	24·8	26·4
Reduction in area	%	35·0	35·0	35·0	35·0	34·1	33·0	33·6	34·7	33·1	33·5
−100°C											
Upper yield point	tons/in²	...	...	27·3	26·8	26·7	27·5	27·2	27·2	27·0	28·0
Lower yield point	„ „	26·0	27·0	26·0	25·9	26·4	26·9	26·9	27·0	25·6	27·0
UTS	„ „	45·0	45·7	45·0	44·8	44·2	44·7	45·6	44·5	45·2	45·7
Elongation	%	27·2	26·8	26·6	23·4	23·0	24·0	25·0	23·5	20·0	20·8
Reduction in area	%	35·0	34·0	33·0	33·0	28·1	30·1	30·6	31·2	28·4	26·5
−120°C											
Upper yield point	tons/in²	...	...	31·5	31·4	30·9	32·3	32·0	30·7	30·0	31·2
Lower yield point	„ „	29·8	30·4	30·8	30·5	30·1	31·4	31·4	30·4	29·2	29·9
UTS	„ „	47·5	47·9	47·2	46·5	47·2	47·2	47·0	46·7	46·8	47·4
Elongation	%	26·5	25·5	23·8	25·2	20·0	21·6	21·6	20·5	16·8	16·0
Reduction in area	%	32·0	32·0	29·2	29·2	25·2	25·8	26·5	27·2	21·1	20·1
−196°C											
Upper yield point	tons/in²	...	...	...	...	...	...	...	...	...	...
Lower yield point	„ „	...	...	...	...	...	...	...	...	...	...
UTS	„ „	56·9	57·8	58·0	55·0	50·4	52·2	51·8	49·8	50·2	52·0
Elongation	%	1·0	1·0	0·4	0·5	1·5	1·5	Nil	Nil	0·8	0·8
Reduction in area	%	1·5	1·5	1·5	1·5	2·2	2·2	„	„	1·0	1·0

properties of a material owing solely to variation in the size of specimen used for its determination. The influence of temperature on size effect is much obscured when there is a variation of these properties with variation of temperature independently of size effect. The size effect, in terms of a difference in some property, measured at different temperatures may have to be compared at different levels of this property with no strict standard of reference.

In tests at room temperature there was evidence of size effect in the reduction in area values, which increased slightly with decrease in specimen size throughout the whole range of sizes used. The increase, 34–37%, was relatively small and most of it occurred at the smaller end of the size range. Size effect also appeared in elongation values, but only with the small test pieces sizes F–A where an increase from 25·5% to 28% was shown. These results are in agreement with those of Miklowitz[1] and Shearing *et al.*[4] There was no clear evidence of size effect at room temperature in the values of yield point or ultimate stress. This was in general agreement with Parker[5] who found no

TABLE III Tensile test results, sizes above 0·10 in²

Test piece size		F		G		H		J		K	
+20°C											
Upper yield point	tons/in²	16·8	16·7	16·6	17·0	16·7	16·9	17·1	16·9	17·1	16·8
Lower yield point	„ „	16·5	16·2	16·0	16·6	16·5	16·5	16·8	16·4	16·4	16·5
UTS	„ „	37·0	36·8	36·8	37·2	37·1	36·8	36·7	36·9	36·8	36·8
Elongation	%	25·6	25·5	26·0	27·7	25·6	25·0	25·0	26·0	25·7	25·4
Reduction in area	%	36·0	35·0	36·6	34·6	35·0	33·0	34·1	34·7	34·4	34·0
−50°C											
Upper yield point	tons/in²	20·8	20·0	20·3	20·2	20·4	21·0	20·5	20·0	20·5	20·3
Lower yield point	„ „	20·0	19·6	19·4	19·8	20·0	19·1	19·8	19·4	19·9	20·0
UTS	„ „	41·6	40·8	40·8	40·8	41·0	40·8	40·4	40·6	40·6	40·7
Elongation	%	26·2	25·5	27·0	26·2	27·2	26·1	27·0	26·5	27·0	25·0
Reduction in area	%	32·8	31·2	33·0	33·9	30·7	30·1	30·0	31·5	29·0	28·5
−100°C											
Upper yield point	tons/in²	27·2	27·5	27·8	27·4	27·8	27·9	26·9	27·9	...	...
Lower yield point	„ „	26·2	26·2	26·4	25·8	26·8	26·6	25·9	26·7	...	...
UTS	„ „	45·6	45·6	45·4	45·8	45·5	45·5	44·9	45·2	...	...
Elongation	%	20·0	19·4	22·0	21·2	21·7	20·8	21·0	20·0	...	...
Reduction in area	%	25·2	23·5	27·1	26·5	24·5	24·1	23·9	22·4	...	...
−120°C											
Upper yield point	tons/in²	31·8	31·7	31·4	31·7	30·5	31·6	31·2	31·0	...	...
Lower yield point	„ „	30·7	30·6	30·8	31·0	29·7	30·5	30·0	30·0	...	...
UTS	„ „	47·2	47·4	46·9	48·0	47·6	47·1	47·2	47·2	...	...
Elongation	%	15·0	16·4	16·3	17·7	15·0	13·9	10·0	11·5	...	...
Reduction in area	%	18·0	19·5	18·4	20·0	16·1	15·0	10·5	12·0	...	...
−196°C											
Upper yield point	tons/in²	...	...	...	...	...	...	...	...	...	...
Lower yield point	„ „	...	...	...	...	...	...	...	...	...	...
UTS	„ „	51·0	51·8	52·2	50·4	50·6	51·6	50·7	50·8	50·7	50·3
Elongation	%	0·7	0·7	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Reduction in area	%	1·0	1·0	„	„	„	„	„	„	„	„



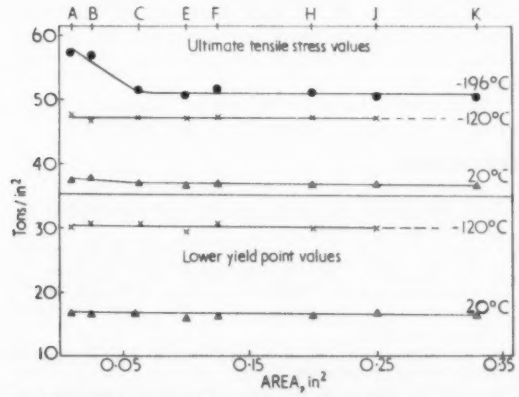
2 *Effect of size on elongation*

pronounced size effect when examining plain mild-steel tensile specimens in sizes up to 40 in² cross-sectional area.

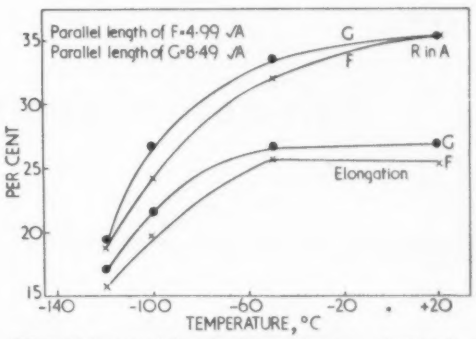
With decrease in temperature there were changes in value of all these properties as determined from test pieces of any given size. In the case of the yield point and ultimate stress, Fig.3, the temperature-induced changes were the same independently of test piece size down to 0·0625 in², and it was therefore evident that within this range variation in temperature did not produce any size effect on these properties. With further decrease in size, ultimate stress values increased from 51·3 to 57·4 tons/in² for test pieces C–A, at very low temperatures. In the case of ductility values, however, the changes which occurred as a temperature effect were different at some temperature level for each test piece size (Figs.1 and 2). These differences were negligible in test pieces down to 0·20 in². Below this size and for a range of temperature between −50° and −120°C, and possibly lower, the decrease in elongation for a given decrease in temperature became much less with reduction in size. Decrease in reduction in area for a given decrease in temperature similarly became less with reduction in size, but this occurred over the whole range of size and over a range of temperature similar to that which applied in the case of elongation.

It appeared, therefore, that size effect was influenced by temperature only in respect of those properties related to strain, and the effect was considerable in amount only when the temperature was between prescribed limits. For the properties related to stress there was no variation of size effect with temperature.

A tendency to embrittlement with increase in



3 *Effect of size on yield and tensile strengths*



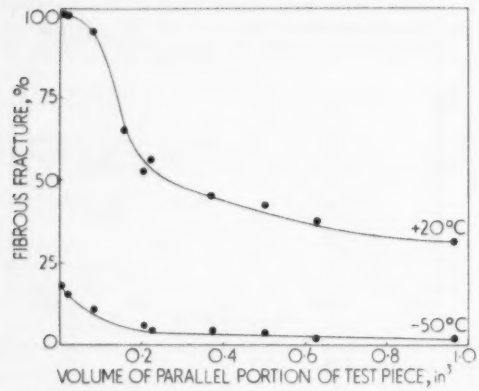
4 *Effect of increased length of test piece on reduction-in-area and elongation values*

specimen size was therefore the only appreciable size effect on the mechanical properties to be observed and this was apparent at all temperatures used in these tests, but it tended to disappear at the upper and lower extremes of temperature. There appeared to be an intermediate temperature at which size effect attained a maximum, which for this material was −120°C or slightly lower. At −120°C, as the test pieces decreased in size from 0·25 in² to 0·01 in², elongation and reduction in area values increased from 10·7% and 11·2% to 26% and 32% respectively.

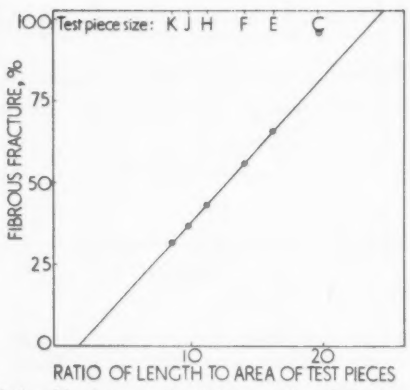
The tendency to embrittlement with increase of size could be explained by the statistical theory of Weibull.[8] It was assumed that failure in brittle materials started from a pre-existing defect or crack and that such defects tended to occur with a frequency distribution varying inversely as their severity. Under these conditions, when the size of the test piece was increased the probability of encountering a greater degree of weakness also increased.

When geometrical similarity of the test pieces was abandoned there appeared to be a tendency for the longer specimens to show greater elongation and reduction in area values than the shorter test pieces of the same cross-sectional area. This is illustrated for test pieces F and G in Fig.4, which is also typical of specimens of sizes C and D. This tendency is based on the average value of duplicate tests, but owing to the scatter in the values obtained the differences between longer and shorter test pieces may not be significant. These differences could arise from an end effect due to the restraining influence of the enlarged grip ends on the deformation within the acting parallel length or, in terms of stress, to the transverse stress gradient generated at the shoulder and transmitted to points within the gauge length. This non-uniform stress distribution would cause premature local yield at the exterior and therefore less apparent ductility.

The fractures of the broken test pieces showed a considerable size effect at room temperature. The amount of fibrous fracture became progressively less as the temperature decreased, and as the specimen size increased. Below −100°C all the tensile fractures, in all sizes, were entirely crystalline. Size appeared to be the dominating factor at all temperatures, within certain limits. There was a lower temperature beyond which size effect on this property vanished because the fractures became wholly crystalline and probably a higher temperature, not reached in these experiments, at which they became wholly fibrous.



5 *Relationship between volume of test piece and fibrous appearance of fractured surface*



6 *Relationship between length/area ratio of specimens and fibrous appearance of fractured surfaces after tests at 20°C*

Although the amount of fibrous fracture varied greatly with the area of the test pieces, it was found that the amount was not an independent continuous function of the area. The proportions of fibrous to crystalline fracture, for the same area decreased with increasing parallel length of the specimen. Measurements showed that the ratio of fibrous to crystalline area varied continuously with the volume of the parallel portion of the specimen, Fig.5, and was, therefore, probably related to the elastic energy stored at the time of fracture. This suggests that the greater the stored energy per unit area of fracture the greater was the fracture speed and the embrittling effect characterized in the fracture by decreased fibrous and increased crystalline areas. To check this relationship it was assumed that for a given stress the stored elastic energy per unit of fracture was proportional to the length/area ratio of the specimen. For the range of geometrically similar specimens of areas 0·10–0·33 in² the percentage amount of fibrous area was found to be inversely proportional to this ratio (*see* Fig.6). The amount of fibrous fracture in these specimens varied from 30% to 70% and by extrapolating these results for room temperature tests on specimens of standard parallel length it was indicated that the fracture would be 100% crystalline for a specimen of area 6·25 in² and 12·5 in. long, and 100% fibrous for a specimen of 0·043 in² area and 1·04 in. long. The fracture of specimen C, with area 0·0625 in² and 1·25 in. long should, according to this extrapolation, have been 80% fibrous, and was found to be 95% fibrous.

CONCLUSIONS

(1) No appreciable size effect for geometrically similar specimens, of an annealed 0·43%C steel to specification En8-V4A/2, was observed in the yield point or ultimate stress value at any temperature, except at −196°C where an increase in UTS was recorded with decrease in size to areas below 0·06 in².

(2) In geometrically similar specimens of parallel length equal to $5\sqrt{\text{area}}$, a size effect appeared in the ductility values at all temperatures from 20° to −196°C, which varied with temperature.

(3) Size effect on ductility attained a maximum at or slightly below −120°C. It decreased to small amounts both at high and low temperatures. The smaller the test piece the lower was the temperature range at which any given decrease in ductility occurred, with the exception that elongation in specimens 0·125 in² in area and upwards was little affected by size at temperatures down to −100°C.

(4) The mechanical properties which showed size effect were those measured in terms of plastic flow and deformation. Properties relating purely to stress or to the threshold of plastic strain were unaffected. The tough-to-brittle transition temperature was dependent on size. There was a critical size at a given temperature which separated ductile and brittle behaviour just as there was a critical temperature for a given size.

(5) The only tensile property which showed a pronounced size effect at room temperature was the appearance of the fracture. With increase in area of specimen from 0·01 to 0·33 in² the fully fibrous fracture was reduced to about one-third fibrous. The effect was very sensitive to change of temperature, a decrease in which produced increased crystallinity.

(6) A relationship was found to exist between the fracture appearance and the volume of the parallel portion of the test piece rather than the area, suggesting that total stored elastic energy before fracture was a factor in determining the type of fracture and the degree of embrittlement exhibited.

(7) The foregoing conclusions can be held to apply only to steels similar to the annealed medium-carbon steel used in these experiments.

ACKNOWLEDGMENTS

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REFERENCES

1. J. Miklowitz: *J. Appl. Mech.*, 1950, **17,** 159–168.
2. P. E. Duwez, D. S. Wood, and D. S. Clark: OSRD Report no.3028, Dec. 1943.
3. I. Lyse and C.C. Keyser: *Proc. ASTM*, 1934, **34,** (2), 202–210.
4. P. E. Shearin, A. E. Ruark, and R. M. Trimble: Conference on strength of Solids, University of Bristol, 1947.
5. E. R. Parker: 'Fracturing of metals': 1947, Cleveland, Ohio, USA, ASM.
6. N. N. Davidenkov, E. M. Shevandin, and F. Wittmann: *Trans. ASME*, 1947, **69,** 63–67.
7. H. F. Hall and R. W. Nichols: *JISI*, 1955, **180,** 330–331.
8. W. Weibull: *IVA* (Stockholm), 1939, report no.151.

Liquidus and solidus relations in iron-rich iron–platinum alloys

R. A. Buckley and W. Hume-Rothery

SYNOPSIS

The liquidus and solidus curves of Fe-*rich* Fe–Pt *alloys have been determined accurately by thermal analysis, and approximate values obtained for the* δ/γ *transformation lines. The system is of the open* γ*-field type, and is remarkable for the extremely narrow freezing range of both* δ*- and* γ*-solid solution alloys. There is a* $(\delta + Liq) \rightleftharpoons \gamma$ *peritectic horizontal at 1519°C, and with increasing* Pt*-content the* γ*-liquidus and solidus probably fall to a very shallow minimum. Comparison of the equilibrium diagrams of the systems* Fe–Pt, Fe–Pd, *and* Fe–Ni *shows that* Pt *has a remarkably high effect in stabilizing the* γ*-phase.* 1726

PREVIOUS WORK on the equilibrium diagram of the system iron–platinum has been summarized by Hansen.[1] The diagram is of the open γ-field type with continuous solid solutions existing at high temperatures between γ-iron and platinum, with superlattices at lower temperatures; of these, the Fe–Pt superlattice is of great stability and persists to above 1300°C. The previous knowledge of the liquidus and solidus was very inaccurate, and nothing was known of the δ/γ equilibrium. The present paper describes work on the liquidus, solidus, and δ/γ transformation lines, as determined by the method of thermal analysis.

EXPERIMENTAL

The platinum used in the present work was supplied by Messrs Johnson, Matthey and Co. Ltd, and was of 99·99% purity. The iron was *H* iron, kindly presented by the British Iron and Steel Research Association, and was of a purity comparable with that used in the previous investigations of this series.[2,3]

The alloys were melted in quantities of about 20 g, and the cooling and heating curves were taken with all the precautions described by Hellawell and Hume-Rothery.[2] Pure alumina refractories were used, and experiments were carried out in a vacuum, and also in an atmosphere of pure argon.

In the early experiments some of the ingots were analysed, and the result showed that the loss in weight during an experiment was due entirely to evaporation of iron. Even when this loss was considerable, the composition by analysis agreed with that estimated from the weights of metal used, after allowing for the loss in weight during the experiment, and assuming that this was due to loss of iron alone. Once this had been established,* it was thought justifiable to base the equilibrium diagram on the compositions estimated from the weights of metals used, and the loss in weight during the experiment.

EXPERIMENTAL RESULTS

The liquidus points were determined from arrests on cooling curves, and the solidus points from heating curves. The accurately determined temperatures for these are shown in Table I, which also gives the results for the δ/γ transformations. In all cases the experimental point lies at the bottom of the triangle for the cooling curve arrest and at the top of the triangle for the arrest of the heating curve.

These results are plotted graphically in Fig.1, which shows that the addition of platinum to iron produces a relatively slight depression of the liquidus and solidus which fall to a peritectic horizontal at 1519°C corresponding to the reaction:

$$\delta\ (2{\cdot}3\ \text{at-}\%\text{Pt}) + \text{Liq}\ (3{\cdot}6\ \text{at-}\%\text{Pt}) \rightleftharpoons \gamma\ (2{\cdot}5\ \text{at-}\%\text{Pt})$$

From this point, the γ-liquidus and solidus probably

TABLE I Temperatures of liquidus and solidus points

Pt, at-%	Arrest points, °C		Pt, at-%	Arrest points, °C	
0	L	1532·7	2·81	L	1520·3
	S	1531·4		S	1515·3
	δ/γ	1389·0	2·82	L	1520·4
		1387·0		S	1517·9
0·7	L	1528·5	3·2	L	1520·0
	S	1526·5		S	1517·0
	δ/γ	1428·0	3·6	L	1520·5
		1432·7		S	1517·0
1·2	L	1526·1	4·27	L	1518·6
	S	1520·7		S	1514·1
1·32	δ/γ	1452·0	4·52	L	1518·9
		1464·0		S	1515·9
1·79	L	1525·0	5·42	L	1521·5
	S	1522·5		S	1517·3
	δ/γ	1480·0	6·0	L	1521·4
2·03	δ/γ	1488·0		S	1517·0
		1494·0	7·1	L	1520·5
2·36	L	1522·5		S	1517·2
	S	1518·2	7·1	L	1521·0
	δ/γ	1503·0		S	1517·0
2·48	L	1523·4	9·75	L	1523·0
	S	1518·9		S	1518·8

Notes: L, Liquidus point from cooling curve.
S, Solidus point from heating curve.
For the δ/γ transformation, the lower temperature is that obtained on the cooling curve, and the higher temperature from the heating curve.

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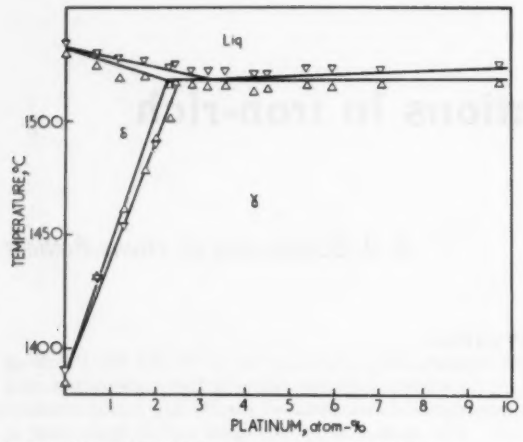
Professor Hume-Rothery and Mr Buckley are at the Department of Metallurgy, University of Oxford.

* Analyses were carried out by Messrs Johnson, Matthey and Co. Ltd, and the authors must express their thanks to Dr J. C. Chaston for his care and attention.



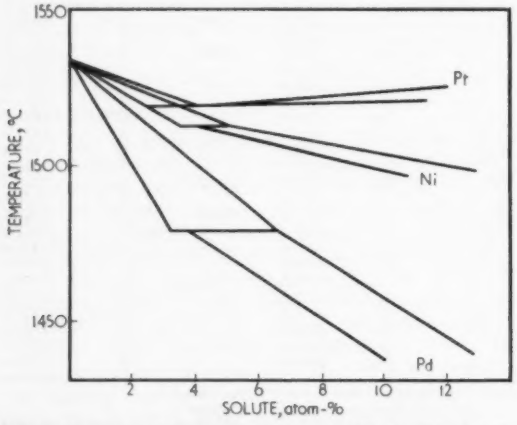
1 *Liquidus and solidus curves for the Fe–Pt systems*

sink to a very shallow minimum, but the depression is too small to be detected by the experimental methods. The liquidus then rises very slowly, and the freezing range remains extremely narrow.

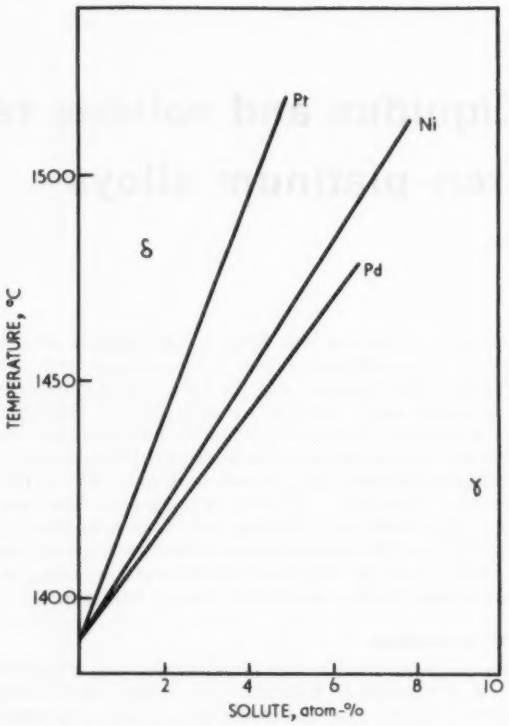
In considering the points shown in Fig.1, it must be remembered that for the pure *H* iron the melting point arrest on heating curves is from 1–2°C lower than the freezing point arrests on cooling curves. In Fig.1, therefore, the most probable diagram is that in which the heating point arrests are raised by 1–2°C since the diagram itself shows the arrest points actually determined.

DISCUSSION

Figure 2 shows the liquidus and solidus curves for the iron-rich alloys of the systems Fe–Ni, Fe–Pd, and Fe–Pt. It was previously considered that the steeper depression of the curves in the system Fe–Pd (as compared with that in the system Fe–Ni) was the result of the larger size factor for Pd. Figure 2 shows that for the δ-phases the liquidus and solidus curves for the systems Fe–Ni and Fe–Pt are nearly the same, in spite of the fact that the atomic diameter of platinum (2·77 kX) is slightly greater than that of palladium (2·75 kX). The difference between the melting points



2 *Liquidus and solidus curves for the Fe–Ni, Fe–Pd, and Fe–Pt systems*



3 *Effect of Pt, Ni, Pd on the on the γ/δ transformation*

of platinum (1769°C) and palladium (1555°C) is only about 200°C, and it is thus hardly likely that such a marked rise in the δ Fe–Pt curves can be ascribed simply to the fact that platinum has a slightly higher melting point. It is perhaps significant that the Fe–Pt superlattice is much more stable than that in the system Fe–Pd, thus suggesting that there is a stronger attraction between unlike atoms in the Fe–Pt system.

Figure 3 shows the effect of the same three elements on the temperature of the γ/δ transformation from which it will be seen that platinum is out of sequence, and produces by far the greatest rise in the A_4 point for a given atomic percentage of solute. Of the elements between Ti→V . . . Ni→Cu in the first transition series, Ni produces the greatest effect in raising the A_4 point, so that the effect of Pt is remarkable.

ACKNOWLEDGMENTS

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REFERENCES

1. M. Hansen: 'Constitution of Binary Alloys', 1958, McGraw-Hill.
2. A. Hellawell and W. Hume-Rothery: *Phil. Trans*, 1957, (A), **249**, 417.
3. W. S. Gibson and W. Hume-Rothery: *JISI*, 1958, **189**, 243–250.

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The design of large gas valves for blast-furnace gas

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SYNOPSIS

This paper describes the nature of problems encountered in the design of blast-furnace gas valves and their possible solution. A brief description is given of the types of goggle valves at present in general use, and is followed by several proposals for improving the accessibility, maintenance, and replacement of the wearing parts.

Several new designs intended to overcome the difficulties met with in high-temperature high-pressure large-diameter valves are described and the general principles to be observed in such designs are discussed. 1640

THE CONVENTIONAL TYPE of plate valve for low-pressure gas is the so-called 'goggle valve' which comprises simply a plate or 'spade' inserted between two flanges of the main. The plate has a full-bore hole in it and the operation consists of removing all but one bolt from the joint and swinging the plate on this bolt so as to present either a blank flange or a full-bore hole across the main. The bolts are then re-inserted and tightened up.

Power or mechanically operated plate valves, which become essential when dealing with hot gas, present problems of considerable interest. It is necessary to arrange that the joint between the valve body and the plate is gas-tight after the plate has been moved. One design using springs is shown in Fig.1. The seal is maintained between the joint and the plate, and because of the tendency of the joint to expand, between the joint and the sides of its recess. On larger sizes of this kind of valve it is common to incorporate a link motion to release the load on the springs before swinging the valve plate, the pressure being re-applied in the new position.

Valves with this kind of sealing mechanism are used for low pressures. For higher pressures, the main features of the designs in current use are shown in Fig.2. The plate is traversed mechanically across a slot in the valve, the slot-width can be varied by axial displacement of the 'floating sleeve'. The sleeve is first retracted, the plate is then traversed to its open (or shut) position and the sleeve forced forward to seal the clearance space and form a gas-tight joint. It is usual to provide the plate with jointing material, such as asbestos gaskets recessed into suitable rings, to improve the seal.

The principle is amenable to many variations. The plate in some valves is of circular or sector form and rotates about a centre instead of sliding. The rams shown in Fig.2 may be hydraulic or pneumatic, or screw mechanism may be used. Some designs use cams or toggles, and since the displacement required is very small, rods thermally expanded by steam jackets have been successfully employed.

As conditions become more arduous, designs which under normal usage function satisfactorily, may be found to be unsuitable. The factors which effect valve design are:

(i) size of main
(ii) pressure of gas
(iii) temperature of gas
(iv) velocity of gas
(v) dirty gas.

Considering these in order: (i) Size always presents problems since the strength/weight ratio of any mechanism or structure varies inversely with the scale. In valve design there is the added problem of

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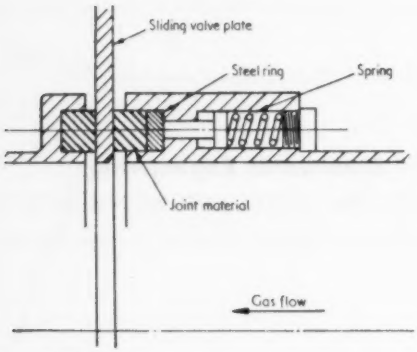
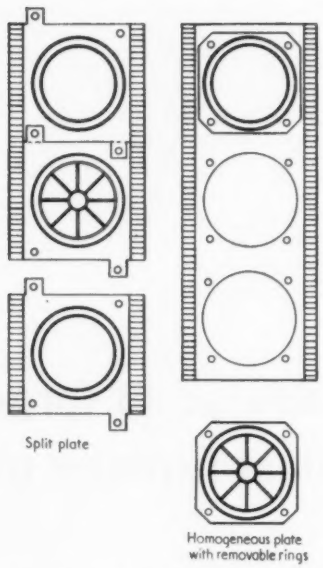


1 *Valve using springs*

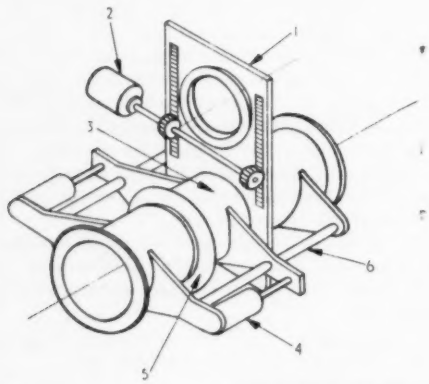
maintaining a gas-tight joint over large surfaces; (ii) Pressure-increase in conjunction with size-increase causes very high loadings on valve parts. For example 40 lb/in² on an 80-in. dia. valve would cause a tension of the order of 90 tons tending to pull the valve apart. This load must be carried by the tie rods shown in Fig 2, and the scantlings must be sufficiently robust to resist any distortion of the working faces. Another problem presented by higher pressures is joint leakage especially in the case of dirty gas; (iii) Temperature of the gas does not, in the ranges envisaged, have any detrimental effect on the properties of the steel used in construction, but it does limit very greatly the materials available for use as joint rings. Rubber gaskets which may be employed most advantageously in many cold-gas installations are completely ruled out; (iv) Gas velocity alone is no hazard but in conjunction with dirty gas will cause severe abrasion; (v) Dirty gas is gas containing particles of matter. This suspended matter may be a soft dust, or may be exceedingly abrasive. Particles of finely sintered ore, or iron filings and turnings from charges of scrap will erode any small projection in a main. In conjunction with high velocities, depressions are not immune, so that small internal clearances are gradually gouged deeper, the process being cumulative until a break-



3 *Two possible designs of valve plate*

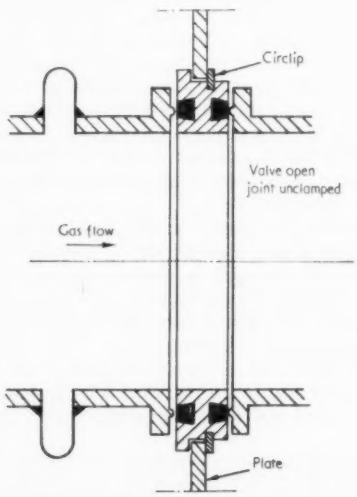
through occurs. It is thus necessary to design all internal surfaces as smooth and flush as possible. With high pressures this trouble is accentuated. If, for example, a very small leakage occurs in a gasket, the escaping gas carrying abrasive particles is akin to a sand-blasting operation and rapidly cuts a large leakage across the jointing face. If this is not quickly detected, the leak will completely destroy the gasket and proceed to cut away the adjacent steel also.

Of the valve of the type shown in Fig.2 the part most likely to fail is the jointing gasket. There are many designs of gasket, which will be considered later, but if the joint comprises a resilient member it is better to position this on the valve plate, with the fixed member wholly metallic. This enables the



(1) Valve plate
(2) Motor operating rack and pinion mechanism
(3) Floating sleeve
(4) Rams actuating the floating sleeve
(5) Flexible bellows
(6) Tie rods

2 *High pressure valves*



4 *Joint using graphited asbestos*

resilient portion to be inspected on the particular ring which is not in use.

Should leakage develop across the joint ring of a valve, then it is necessary to shut off the valve to inspect the joint, and if the erosion is serious, it may be necessary to shut down the whole line to remove the goggle plate for repair.

To eliminate this trouble an improved valve plate is used in which, instead of just two positions there are three or more. Moreover, each joint mounting can be detached from the plate and replaced by a serviced one, the old one then being repaired at leisure. In this way, if the valve is open and develops a leak the plate can be racked over to a spare open port and thus keep the plant in operation.

Figure 3 indicates two general methods by which this may be achieved. The left-hand diagram shows a split plate, each section of which may be removed complete with its jointing rings, rack sections, and limit-switch dogs. This principle is very flexible, in that a two-, three-, or four-ported valve can be built as desired, and if the valve is used for long periods in a fixed position all segments may be removed except that one actually in operation, for it is a simple matter to attach the adjacent segment in position some time before a changeover is required. The right-hand diagram illustrates a homogeneous plate with plain holes. Into these holes annular gasket ring frames, or gasketed blanking-off plates may be inserted.

For a large gas valve the thickness of the blanking ring is considerable, e.g. for an 80-in. dia. valve at 40 lb/in^2 a 3-in. solid plate is necessary, or if a hollow fabricated disc is used, a thickness of the order of 6 in. would be envisaged. This thickness allows ample space for the bolts, as shown in Fig.3.

The plate itself carries no load. It is merely a carrier, and there is no need for a gas-tight joint between the gasket rings and the plate. Because of this, several simple and quick attachments of the rings to the plate are applicable. Figure 4 shows a simple circlip attachment which serves this purpose admirably.

Although rectangular sliding goggle plates have been illustrated these principles apply equally to rotating sector plates.

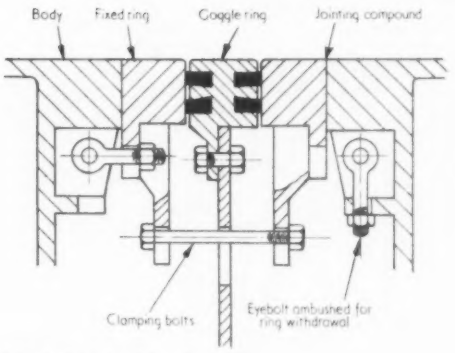
The second most likely cause of failure on a gas valve is erosion of the fixed seat. In the case of metal-to-metal joints, erosion would be expected to be shared between the moving or plate seat faces and the fixed seats, and severe erosion resulting in cutting away a resilient gasket might be expected to score the adjacent fixed seat.

According to the method of valve construction it is possible to attach the fixed seat to the valve body by a ring of bolts, usually sealed against the body with sealing compound. By fixing lugs to the static rings with clearance holes through the goggle plate it is possible to carry the fixed ring with the goggle plate and so to replace rings in service.

The sequence would be as follows:

(i) attach a spare pair of rings on either side of the goggle plate clamping an unused joint ring
(ii) treat outer faces with jointing compound
(iii) unbolt existing rings from body
(iv) clamp existing rings across the joint ring at present in use

(i)–(iv) may be done with the valve in operation at any time before the desired switchover



5 *Valve body using hinged eyebolts*

(v) unclamp the valve by means of the unclamping mechanism. Instead of the seats parting in the normal way the fixed rings will be parted from the body
(vi) rack the goggle plate through to the new position and clamp up valve.
The valve is now still in operation, and the remaining work may be done at any time
(vii) bolt the new fixed rings in position and remove the bolts holding through the goggle plate
(viii) remove the old rings from the goggle plate for repair or disposal.

Figure 5 illustrates this principle. Although ordinary bolting may be used throughout, hinged eyebolts for attaching the fixed rings and slotted holes for the clamping bolts will facilitate the operation.

The only other vulnerable item of a gas valve is the bellows. Whereas an equipment similar to the above could also be applied to removal of the bellows on the goggle plate, this would involve additional clamping bolts etc. for pretensioning the bellows and would complicate the general design in that the bellows would be mounted in front of the clamping gear. The main objection, however, would be the very large section of the main temporarily exposed during transition of the bellows, and the fact that the rear bellows joint would blow gas until rebolted, necessitating the presence of engineers in a toxic atmosphere. A method of achieving bellows change is discussed later.

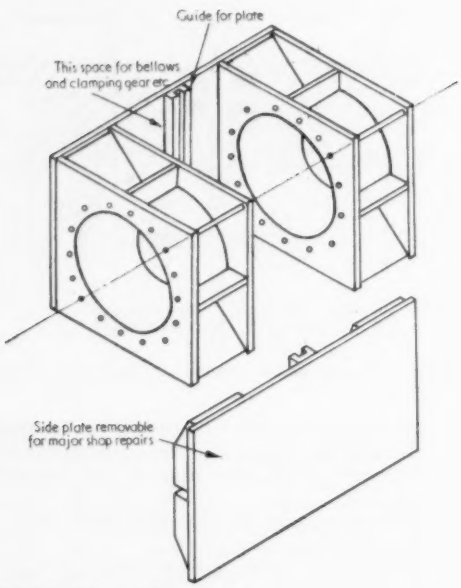
Body construction

There are no great problems involved in body design. It is only necessary to obtain sufficient strength and rigidity, and attachments etc. for the working parts. Consideration must also be given to accessibility of the components for maintenance and replacement.

As far as body construction is affected there are two types of valve in common use. The semi-flexible valve, which does not use bellows but relies on the deformation of the adjacent main to give the slight displacement required for unclamping, and the full beam strength valve, which incorporates its own flexible bellows, and is of fixed length between the flanges.

The former design is much simpler, but normally requires to be supported and guided and is not applicable in congested areas where flange distances have to be accurately maintained.

This paper is concerned with the latter type. A fully rigid valve must be sufficiently strong to be inserted



6 *Typical sliding-plate valve body*

into a main without additional support. To achieve this it is only necessary to ensure that the nett strength of the valve in tension, compression, and bending is equal to or greater than that of the uncut main.

The gross strength may be greater, e.g. a valve using springs to clamp the goggle plate superimposes an additional tension on the valve tension rods in excess of that caused by gas pressure only (*see* Fig.2).

A typical sliding plate valve body is shown in Fig.6. Here the longitudinal tension is taken by a pair of side plates which are removable for major repairs such as welding and machining. It will be seen that the load is carried from the cylindrical base tube by means of ribs on to a boxlike structure to which are attached the side plates. It is apparent that the wider the side plates are disposed, the deeper the box frames become to keep the stresses down, and this therefore increases the overall length of the valve. It is important, therefore, to keep the clamping gear, bellows, and goggle-plate assembly to a minimum width to produce a valve of reasonable overall dimensions.

In the case of a rotating valve, side plates as shown in Fig.6 cannot be used. It is conventional in this case to use a triangular box frame with three tensile rods or tubes.

Clamping mechanisms

Clamping mechanisms may be divided broadly into two types; (*a*) finite displacement mechanisms and (*b*) finite load mechanisms. A third class (*c*) uses a finite load and locks at its initial displacement.

The type used depends largely on the type of joint. With a metal-to-metal joint, then obviously type (*a*) giving a finite displacement will either overstress the valve, or come short and leave a space for gas leakage. The possibility of adjusting the stroke so that the faces just meet under all temperature conditions is remote.

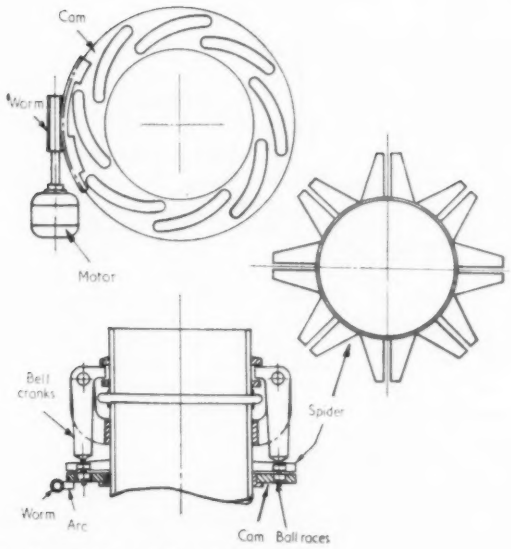
Again, if the joint makes use of a pliable but not very elastic gasket, e.g. woven copper and asbestos mating with a sharp steel ridge, then type (*b*) would cause the ridge progressively to bite deeper and deeper into the gasket until the latter was completely destroyed.

Treating these mechanisms in order: (*a*) This principle lends itself to various mechanical link motions, e.g. toggles, eccentrics, bellcranks etc. and screws of preset stroke. In these the gap is opened sufficiently to allow the goggle plate to swing, and closed to the same gap each time. It is used extensively on the type of joint shown in Fig.4, namely a dimpled fixed ring and a graphite-impregnated gasket in the goggle ring. (*b*) This principle is usually achieved by means of springs. The sleeve is thrust forward to close the gap under a spring load of specified magnitude. To unclamp, the springs are retracted mechanically, one type employing hydraulic rams for this purpose. One advantage of this principle of clamping is that the sleeve 'follows up' any gap alteration due to tempera-ture fluctuation or any other cause, and the pressure on the joint face is maintained continuously. Other means of achieving this type of clamping are by hydraulic or pnematic rams acting either directly or through a link motion. These methods, although perfectly workable, rely on an external source of force, e.g. a hydraulic accumulator or compressed-air system, and it would only be reasonable to contemplate them for very large valves. (*c*) As a compromise between (*a*) and (*b*) a clamping gear may be used employing screw mechanism, power-operated through a slipping clutch. In this case, on applying the clamping stroke, the gap closes up until a predetermined load is imposed on the joint faces. The clutch then slips, and the motor can be switched off. If the gasket is of a material subject to creep, the sleeve will not follow up and distort it indefinitely.

Thus there are applications for each of these clamping principles according to the type of jointing used. Whatever the form of clamping gear it is important for the loads or displacements to be equally disposed round the sleeve perimeter, and if auxiliary link motion is used the gear should be arranged so that no station suffers from more backlash than any other.

As an illustration of this, Fig.7 shows a bellcrank link-motion actuated by a rotating cam, and so disposed that the loading is symmetrical and also the strains in each bellcrank will be equal for a given loading.

It is usual to mount the cam actuating gear as in Fig.2, i.e. disposed entirely at one side of the goggle plate. When the valve is clamped up, the loads are thus taken back to the valve end frames and then across the tensile rods. It follows that the total strain in all these members may cause a significant alteration in the gap. One scheme to overcome this has a circle of retractable rods on the floating sleeve arranged to feed through clearance holes in the goggle plate and engage a ring on the body at the fore side. Tension put on to this ring clamps the goggle ring between the sleeve and body by the most direct and positive means, and throws no additional load on the main valve structure. This is shown diagrammatically in Fig.8. A headed screw with a long keyway, motorized from some point on the valve body, engages a nut on the sliding sleeve. Once the goggle ring is in position the screw is rotated,



7 *Clamp using a bellcrank link-motion*

thus feeding forward, through the clearance holes into the ring on the adjacent body member. The locking ring is then rotated, which engages under the screw head. Reversal of the screw drive then draws the joint faces together and clamps the goggle ring. In the arrangement shown, several such screws would be disposed equally round the body perimeter driven by a common roller chain.

An arrangement of this nature is only of value to types (*a*) and (*c*) clamping gear, since in type (*b*) the springs will follow up any fluctuation in the gap.

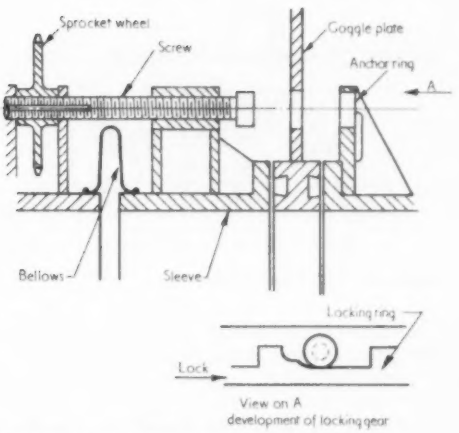
Racking gear

The equipment used to displace the plate, whether sliding or rotating, can be by means of rack strips (or arcs) or roller chain, or even wire rope. Wire rope, especially if working with a counterweight, gives a smooth motion but is not as positive as a meshing chain.

One advantage of using rack and pinion mechanism is that segments can be removed along with their section of rack (Fig.3, left-hand diagram), but otherwise chain operation is quite satisfactory.

It is common on large sliding valves to guide the goggle plate between rollers to reduce the friction. In the conventional valve with the clamping sleeve at one side, it is necessary for the plate to have some axial play so as to free itself from the rigid face of the valve body. On some designs ramps are built into the valve plate guides to draw the goggle plate into a central position clear of the gaskets as soon as the plate begins to move. Such an arrangement is simple but not entirely satisfactory, since some dragging must occur as the plate begins to move. A more satisfactory arrangement is for the plate guides to be drawn central as the valve unclamps, thus breaking the seal before the plate is racked.

With triple-ported plates, a difficulty to be faced is the correct centring of the plate port before clamping up. On mechanically operated valves, the first stage is



8 *New type of valve-clamping mechanism*

to fit limit switches with dogs on the goggle plate. These would cut out the racking motor at some preset point and allow the plate to come to a standstill at the desired position. There are, however, several variables to be allowed for. The weight of the plate will affect the stopping distance depending on whether the plate is rising or dropping. The friction on the guides will vary according as the valve is closing or opening, (e.g. a 4-ft valve working at 20 lb/in^2 will receive a load of 15 tons or so on a blanked plate, and taking the coefficient of friction as 0·3 this amounts to a resistance to movement of 4½ tons). Therefore alteration in the working pressure will also affect the time taken in coming to a standstill.

End ports may be equipped with fixed stops, but intermediate ports should have some form of retractable stop which will drop into position at the correct position yet be retractable for the next time the valve is to be racked. With this arrangement the limit-switch dogs would be adjusted to allow the plate to overrun its correct position, the mechanical stop arresting it positively at the true location. To reduce inertia loads, a slipping clutch should be incorporated between the drive and the final shaft.

Joint seats

Several different forms of joint are in common use, and these will be mentioned without comment:

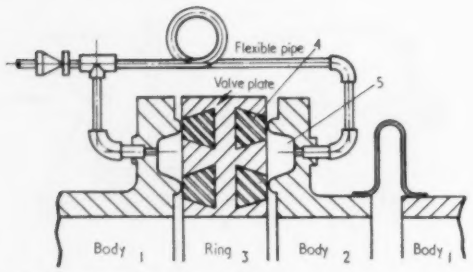
(i) metal-to-metal joint. This can take the form of flat annular surfaces of steel, or alternatively of dissimilar metals such as steel and copper. In some designs a neoprene ring is let into a dovetailed slot in the metal face as an additional precaution against leakage

(ii) laminated rubber against a flat metal surface. This is illustrated in a simpler type of valve in Fig.1

(iii) graphited asbestos borne against by a metal 'pimple'. This is shown in Fig.4. The asbestos is hammered into a dovetailed recess on the goggle ring and the body ridges bite into it

(iv) copper–asbestos fibre against steel. This is assembled in a similar way to that shown in Fig.4.

The main problem of seating is temperature. If a



9 *Pressurized seal to prevent leakage*

material with the properties of rubber and withstanding the temperatures obtaining in blast-furnace gas-mains were available, the sealing problem would vanish. Graphited asbestos will take the temperature but gradually hardens and embrittles. The metallic seats are not affected by temperature, but for larger sizes become difficult to make truly flat.

There are two schools of thought concerning the problem of ensuring that metal seats remain gas-tight. One holds that the floating sleeve should be relatively long so that the machined surface is rigid. The other favours a flexible surface obtained by a very short floating sleeve, with as many clamping points as possible. It is claimed that this will cause the sleeve to bed on the goggle ring, which in turn will bed on the rigid face of the body. Obviously such an arrangement depends on careful design, in that excess flexibility will permit leakage at those points midway between adjacent clamp rams.

Bellows

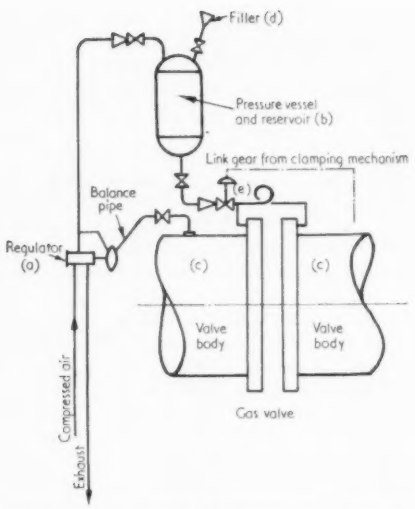
The usual type of bellows used on goggle valves has one convolution, and is made from relatively thick steel. Since the stroke required is usually very small this is usually sufficient, but if it leads to an excessive diameter of bellows affecting the valve body width (*see* p.65) then two or more convolutions should be considered.

It is normal to sleeve the bellows internally to help prevent ingress of dust, but even when valves are bricked over this internal sleeve, dust does tend gradually to infiltrate into the bellow space. Because of the action of the bellows, i.e. compressing for short periods under large forces and remaining extended for long periods, the dust tends to pack progressively tighter into the bellows space. If this state of affairs is allowed to continue indefinitely, the bellows will sooner or later become solid, and the valve will refuse to unclamp.

Some manufacturers supply one or more plugged holes in the bellows for draining moisture and presumably blowing through to clear out dust.

In other industrial applications, dust is kept clear of bellows by means of a deflector tube located just before the bellows, which produces sufficient local turbulence to prevent dust settling in that area. Such an arrangement might prove to be more effective than a close-fitting internal sleeve.

Another possibility might be to fill the bellows with a suitable viscous material capable of remaining stable under the operating temperature, even e.g. silicone rubber. This would prevent dust occupying the bellows space yet allow the bellows to breathe.



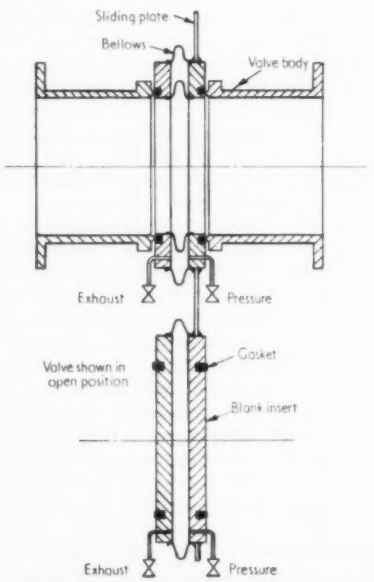
10 *Arrangements for sealing the interannular space with fluid under pressure*

Special designs

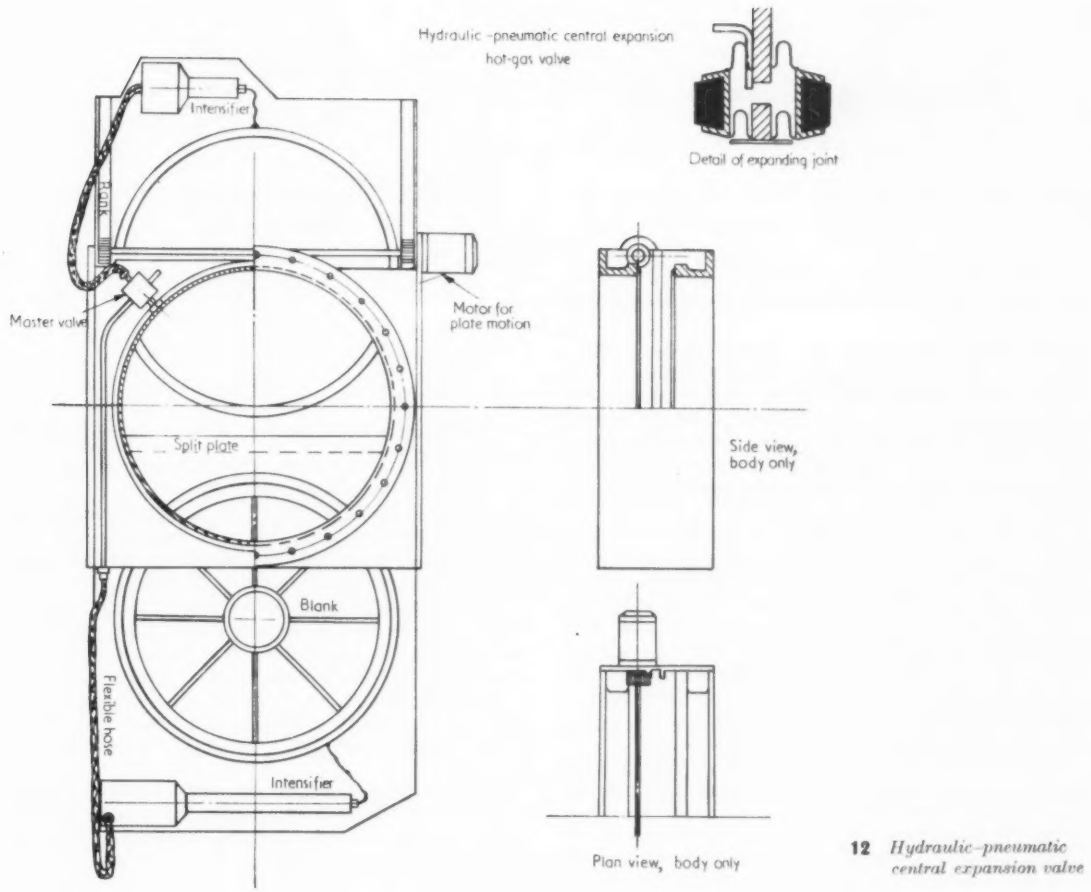
The following principles intended at overcoming some of the problems met with in large high temperature, high pressure valves, are illustrated for general interest.

Pressure sealing The diagram in Fig.9 illustrates a way of pressurizing the space between concentric joints with a view to reducing leakage.

Leakage at first must obviously be very small, but it rapidly increases due to the erosive effect of the escaping gas. By pressurizing the interannular space with a clean fluid at a pressure slightly above that of the main, we obtain the following conditions: (*a*) leakage in the inner gasket causes a slight flow into the



11 *Proposed design of valve incorporating expanding gasket*



12 *Hydraulic–pneumatic central expansion valve*

main of clean fluid. Owing to the very low pressure differential the quantity flowing would be very small. The leak would not tend to increase because of the clean nature of the sealing fluid; (*b*) leakage in the outer gasket causes a visible leak of clean fluid which should remain constant because the sealing fluid is non-erosive; (*c*) the nature of fluid used must be such as not be harmful to the blast-furnace gas. Compressed air, for example, would be a source of danger as it could cause an explosive mixture in the main. Clean compressed blast-furnace gas itself would be suitable, or any viscous fluid capable of resisting the temperature.

A typical arrangement is shown in Fig.10. This is pressurized by compressed air through a regulator which reduces it to a level slightly above that obtaining in the main. This puts the reservoir of sealing fluid under pressure, which is then led to the interannular sealing space. A motorized valve automatically isolates the system before unclamping and re-applies it after clamping. Suitable non-return valves and hand isolating-valves are incorporated for charging the reservoir, etc.

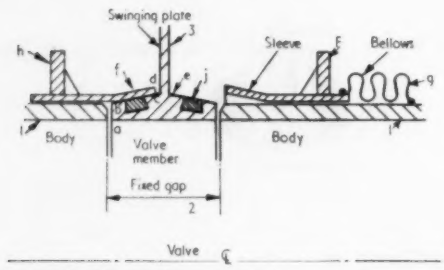
This principle might be extended to the use of a self-sealing compound which would seal any leaks as they developed.

Expanding gasket In an attempt to render the bellows accessible for maintenance the design shown diagrammatically in Fig.11 is proposed. In this the body is rigidly constructed and the gap through which the goggle plate moves is of fixed width. The goggle plate carries twin joint-rings separated by bellows, these bellows being thrust apart by means of hydraulic pressure introduced into the intervening space.

A development of this principle, Fig.12 illustrates a hydraulic–pneumatic central expansion valve with only two ports. The plate is split and each plate carries an integral expanding gasket connected to an intensifier. There is a fixed quantity of hydraulic oil and the whole assembly is bellows-sealed to prevent leakage. The intensifiers are operated by compressed air from an electrically operated master valve. This valve is coupled to the racking-motor circuit to cause the bellows to collapse before swinging and to expand when in the correct position.

For maintenance, the inoperative half of the goggle plate can be unbolted and the flexible compressed air hose uncoupled, so that the whole can be replaced by a repaired or new unit.

Conical seal Comparing rigid with flexible metallic joint seats we are led to a concept of seating and clamping gear of a somewhat different form. This is



Section showing one sleeve retracted

13 *Valve design which has both rigid and flexible characteristics*

shown diagrammatically in Fig.13. Body 1 has a gap 2 of fixed width. Goggle plate 3 has wide seating rings, whose sealing surfaces are shallow cones. The clamping gear consists of two female cones *f* attached at one end to bellows and actuated by the clamping gear. Clamping is effected by thrusting the cones towards the goggle plate, and unclamping by retracting them beyond the gap.

The underlying principle of this mechanism is as follows: flanges *h* are of robust construction and the cylindrical and conical parts of the sleeve *f* are relatively long. Hence the sleeve is very rigid axially. The cone and cylinder are thin, however, and thus the cone is flexible diametrically. Goggle ring *e* is relatively thick and rigid. When the sleeves are thrust on to the goggle ring they bed themselves on any inaccuracy in the concentricity of the ring, and in fact on to any small irregularity provided it remains convex.

Theoretically the sleeve should be conical (female) and the goggle ring should be spherical, thus ensuring contact over a complete circle.

On Fig.13 gaskets *j* are shown as an alternative to metal-to-metal joints. Here the same principles apply.

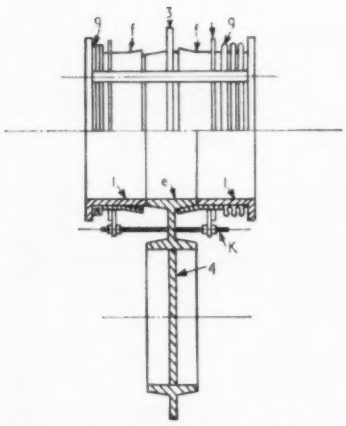
A valve embodying the conical seal possesses several other advantages, and a few disadvantages. These disadvantages are:

(i) need for two long-stroke bellows
(ii) large gap for gas leakage when swinging
(iii) duplication of clamping gear.

The advantages are:

(i) simplification of valve body design
(ii) bellows space well clear of main flow and dust
(iii) goggle plate load taken by body (not seal)
(iv) leakage path very indirect.

The long-stroke bellows can be made from stainless steel, which allows them to be thin and flexible with-



Valve in open position, one sleeve retracted, clamping gear not shown

14 *Diagrammatic arrangement of the valve shown in Fig.13*

out the need for a corrosion allowance. For the same reason the sleeve can also be made from stainless steel and the sleeve flange and bellows supplied as a welded assembly for bolting on to the mild-steel body.

The clamping gear consists of a mechanism connecting the two flanges. Four rods screwed left and right (*see k*, Fig.14), and geared together, serve this function admirably. The whole clamping gear would be allowed a limited float and would locate on the goggle ring. Thus the end-loads on a closed ring would be taken wholly by the body, and would in no way strain the joint face.

Should leakage develop, the path of escaping gases is along *a–b–c–d* (Fig.13) which, being zigzag, will reduce the gas velocity, and the resulting erosion, to a much greater degree than in the case of the conventional valve.

If the large gap obtained when swinging is considered serious this can be reduced considerably by thickening the goggle plate to the same thickness as the rings, allowing the annular recesses to clear the outside diameter of the conical sleeve.

ACKNOWLEDGMENT

The author wishes to acknowledge that the concept of removing and replacing valve seatings *in situ* originated from the engineers at the Bilston works of Stewarts and Lloyds Ltd, who have successfully applied this principle.

NEWS

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Autumn General Meeting

The Autumn General Meeting of the Institute will be held in London from Wednesday to Friday, **2 to 4 December.** The main technical sessions will be devoted to the presentation and discussion of a series of papers on hot and cold deformation, including forging and extrusion. There will also be sessions devoted to the evolution and prevention of fumes in steelmaking processes and to metallurgical subjects. Full details will be published in a later issue of the *Journal*.

Twelfth Hatfield Memorial Lecture

The Twelfth Hatfield Memorial Lecture will be delivered at Sheffield on the evening of Wednesday, **25 November,** by Academician G. Kurdjumov, of the Department of Physical Metallurgy, Central Research Institute for Ferrous Metallurgy, Moscow. The subject of the lecture will be *The phenomena occurring in steels during quenching and tempering.* Full details will be announced later.

Joint meeting on corrosion

A joint meeting of The Iron and Steel Institute and the Corrosion Group of the Society of Chemical Industry is being held on Thursday, **15 October,** at 2 pm to discuss the Sixth Report of the Corrosion Committee, which was published recently as No.66 in the Institute's Special Report Series. Joint chairmen of the meeting will be Dr U. R. Evans, F.R.S., and Mr L. Kenworthy.

Admission to the meeting, which will take place at the rooms of the Society of Chemical Industry, 14 Belgrave Square, London SW1, will be by ticket only; tickets may be obtained on application to the Secretary of The Iron and Steel Institute.

Symposium on determination of gases in metals

The Society for Analytical Chemistry, The Iron and Steel Institute, and The Institute of Metals are holding a joint symposium on Tuesday and Wednesday, **3 and 4 May 1960,** at Church House, Great Smith Street, London SW1, on 'The determination of gases in metals'. Three sessions are envisaged, occupying the afternoon of the Tuesday and the morning and afternoon of the Wednesday. At the first session, invited review papers will be presented, covering the determination of oxygen, hydrogen, and nitrogen respectively in a general way; the other two sessions will be devoted to shorter papers and discussions dealing with specialized aspects of the field.

It is intended that preprints of all the papers shall be available before the start of the symposium, and that the proceedings, including discussions, shall be published in a single volume at a later date.

Darby Anniversary Meeting

In 1709 Abraham Darby achieved the first successful use of coke in ironmaking at Coalbrookdale. To celebrate the 250th anniversary of this event, a meeting will be held from Wednesday to Friday, **23 to 25 September,** at the University of Birmingham and at Coalbrookdale, Shropshire.

Allied Ironfounders Ltd have made arrangements to preserve the furnace and to establish a museum on the site of Abraham Darby's experiments at Coalbrookdale. A committee set up under the chairmanship of Sir Frederick Scopes is organizing the meeting.

The following is an outline programme of the meeting:

WEDNESDAY, 23 SEPTEMBER

Evening

Opening lecture at the University of Birmingham by Professor T. S. Ashton on *The economic and social background of the iron industry in the eighteenth century.*

THURSDAY 24 SEPTEMBER

All day

Presentation and discussion at the University of Birmingham of the following papers:

The charcoal iron industry in Great Britain, with special reference to Shropshire and the development of the industry up to 1750, by B. L. C. Johnson.

The contributions of the Darby family to ironmaking and the iron industry, by Dr A. Raistrick.

Coalbrookdale 1709, by Dr R. A. Mott.

Ironfounding past and present, by Dr J. G. Pearce, C.B.E.

Evening

Dinner at the Grand Hotel, Birmingham.

FRIDAY, 25 SEPTEMBER

All day

Visit by motor coach to the Coalbrookdale furnace and museum, the Iron Bridge, and other historical sites in the neighbourhood.

Further details and forms of registration may be obtained from the Secretary, The Iron and Steel Institute.

Archaeological Enquiry Scheme

By arrangement with the Council for British Archaeology, the Institute has organized a scheme by means of which archaeologists may enlist without charge the help of metallurgical research laboratories for the examination and analysis of iron objects from antiquity. So far seven laboratories have promised to cooperate in the scheme, which involves the analysis and metallographic examination of iron objects, slags, and refractory materials. Other laboratories or individuals interested in joining in the scheme are invited to write to the Assistant Secretary at The Iron and Steel Institute.

NEWS OF MEMBERS

Mr **A. Ash** has left F. Braby and Co. Ltd to become technical service engineer with the Consolidated Mining and Smelting Company of Canada Ltd.

Mr **W. Barr,** O.B.E. (*President*) has been elected a vice-president of the Institute of Welding.

Mr **H. J. Gamble** has joined Richard Thomas and Baldwins Ltd, Coed Parc, Bridgend, as a mechanical engineer.

Professor **P. Coheur** is now Administrateur Gérant of the Centre National de Recherches Métallurgiques (Section de Liège).

Dr **T. P. Colclough,** C.B.E. has been awarded an honorary degree of Doctor of Metallurgy by the University of Sheffield.

Mr **A. Cress** has been appointed blast-furnace adviser to the Companhia Siderurgica Nacional, Volta Redonda, Brazil.

Mr **J. V. Emmons** is now metallurgical and research consultant to the Cleveland Twist Drill Company.

Mr **J. B. France** is now sales manager of Lockers (Engineers) Ltd.

Señor **A. Goyoaga** has relinquished his position as managing director of Altos Hornos de Vizcaya S.A., Bilbao, on appointment to a seat on the Board of Administration of the Company.

Dr **H. T. Hall** has relinquished his lectureship in metallurgy in the Faculty of Technology of the University of Manchester to become head of the Metallurgical Department at the County Technical College, Wednesbury.

Mr **A. R. Madsen** has left Vickers-Armstrong (Tractors) Ltd to become works metallurgist with Jarrow Tube Works Ltd.

Dr **Robert F. Mehl** has been awarded the Vincent Bendix Gold Medal of the American Society for Engineering Education; he has also recently been awarded honorary degrees by the Case Institute of Technology and the University of Pennsylvania. Dr Mehl has relinquished the position of Head of the Department of Metallurgical Engineering at the Carnegie Institute of Technology in order to devote additional time to research; he will remain Dean of Graduate Studies and Director of the Metals Research Laboratory.

Mr **R. Rolls** has been awarded the degree of M.Sc. by Durham University; he has also been elected to Associateship of The Institution of Metallurgists.

Dr **E. T. Turkdogan** is leaving BISRA to join the Fundamental Research Laboratory of the United States Steel Corporation.

Mr **S. Walsh** has joined the staff of the UK Atomic Energy Authority.

Obituary

Mr **John Ambrose Matthews,** M.I.MECH.E. (*elected* 1945), of London, on 22 July 1959.

Sir **Frederick Pickworth** (*elected* 1936), of Sheffield, on 14 July 1959.

Mr **Arnold Stanley Pye-Smith,** B.A. (*elected* 1900), of Sheffield, on 6 July 1959.

IRON AND STEEL ENGINEERS GROUP

Meeting of junior engineers in Glasgow

A meeting of junior engineers is being held in Glasgow on Wednesday and Thursday, **28 and 29 October.** There will be a technical session on the Wednesday morning, and in the afternoon a visit to the Ravenscraig works of Colvilles Ltd. On the Thursday, there will be alternative all-day visits to the General Terminus Quay, Clyde Iron Works, and Clydebridge Works of Colvilles Ltd, or to the Clydesdale Steel and Tube Works of Stewarts and Lloyds Ltd and to the works of the North British Locomotive Co. Ltd.

POWDER METALLURGY JOINT GROUP

Forthcoming meetings

A symposium on 'The powder metallurgy of magnetic materials' is to be held at Church House, Great Smith Street, London SW1, on Wednesday, **16 December.** It will be based on a series of invited papers describing original work, all of which are to be published in *Powder Metallurgy*, Part 4, which will be available before the meeting.

The Spring Meeting of the Joint Group will be held at Church House on Monday and Tuesday, **11 and 12 April 1960.** The subject of the meeting will be 'Continuous processing in powder metallurgy'.

AFFILIATED LOCAL SOCIETIES

Staffordshire Iron and Steel Institute

The Officers and council of the Institute for the 1959–1960 session are as follows:

President L. W. Law, M.A., M.I.E.E.
Senior Vice President
F. V. Wright, A.M.I.MECH.E.
Junior Vice President
M. R. Liddiatt, A.I.M.
Trustees P. Jump, M.I.MECH.E.
H. E. Cookson, T.D.
W. H. Lewis, M.I.MECH.E.
Hon. Auditors F. S. Woodward
D. M. Groome
Members of Council
P. C. Brooks
H. C. Davies, A.M.I.MECH.E.
W. K. V. Gale
E. B. Gibbons, M.I.G.E., M.INST.F., J.P.
G. T. Hampton, F.I.M.
H. J. E. Jones, M.C., B.A.
L. Harper
T. Morfey
C. Macquarie, B.SC., A.R.C.S.T., F.I.M.
G. Harrison, J.P., A.M.I.M.E.
Members of Council (Past Presidents)
A. Biddulph, A.I.M.
K. H. Wright, F.I.M.
K. G. Lewis, M.SC., M.SC.(TECH), F.I.M., F.R.I.C.
A. W. Shore, A.M.I.STRUCT.E.
W. H. B. Wesson, T.D.
Secretary G. Riley, A.M.B.I.M.

The 1959 Annual Essay Competition of the Staffordshire Iron and Steel Institute is open to associates and members of the Institute below the age of 28. They are invited to submit a paper of a practical nature of 2500–3000 words on one of the following subjects: iron-making, steel manufacture, foundry work, hot and cold working of steel, fuels, refractories, and engineering. The closing date for submission of papers is 31 December 1959. The announcement of the award, of ten guineas, will be made at the Institute's Annual General Meeting in 1960. Forms of application may be obtained from the Secretary, G. Riley, Stewarts and Lloyds Ltd, Bilston Iron and Steel Works, Bilston, Staffs.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Open days at Battersea

Two open days are to be held at the BISRA laboratories at Battersea Park Road, London SW1, on Thursday and Friday, 22 and 23 October.

The open days will provide an opportunity for showing the work of BISRA's London Group laboratories, which besides the Battersea premises include part of the Ironmaking Division housed at the Imperial College of Science at South Kensington. The Battersea premises house the laboratories of the Association's Plant Engineering and Energy Division, and the Departments of Physics, Chemistry, and Operational Research.

In the Plant Engineering and Energy Division's laboratories, the electrical engineering section will display the extensive work being done on electrical control and recording; this will include the 'Tallimarker' apparatus, one of the latest developments in information handling. The civil engineering section will be showing work on the design and testing of girder and gantry structures, whilst the mechanical engineering section will display a number of projects relating to the handling of bulk materials, and hydraulic and other control systems for steelworks' plant. The recently formed energy section will mount displays relating to an inquiry into the fuel consumption of the industry.

In the Physics Department, the new automation section will be showing one of its first projects, involving the automatic deseaming of billets. The instrument section will highlight several projects in support of the premise that instruments are the first step towards automation, while the metal physics section will show something of the continuing investigations into the problem of combined creep and fatigue.

The Chemistry Department will be featuring the work of its physical chemistry, corrosion, and refractories sections. The last-named will be showing a development in OH furnace roof design which has been shown in production tests to offer a longer working life than conventional design.

The Operational Research Department, besides showing the work of its computer application and human factors sections, proposes to highlight the work of its operational investigation section, which has already carried out studies on behalf of a number of firms throughout industry.

A special display of one of the most important projects of the Ironmaking Division is being prepared, to illustrate the principle of the recently-developed 'SCICE' (Stationary Charge In Controlled Environment) apparatus.

The open days will also give visitors the opportunity of seeing the considerable structural alterations that have taken place at Battersea. This is the first step in a long-term plan for the complete rebuilding of the premises.

Formal invitations to the open days will be issued to BISRA member firms very shortly. A general invitation is, however, extended to all those interested in the engineering and technical problems that concern the iron and steel industry. The Information Officer of BISRA at 11 Park Lane, London W1, will be glad to hear from those wishing to attend.

BRITISH NUCLEAR ENERGY CONFERENCE

Symposium on nuclear energy

The Institution of Chemical Engineers is sponsoring a symposium on nuclear energy, to be held at the Royal Institution, Albemarle Street, London W1, on Tuesday, 24 November, at 2.30 pm.

The following papers will be presented and discussed:

The second uranium production plant at Springfields, by R. C. Alexander, L. P. Shortis, and C. J. Turner
The processing of uranium ores and concentrates to purified uranyl nitrate solution, by H. Page, L. P. Shortis, and J. A. Dukes
The fluidized solids dryway process for the production of uranium tetrafluoride, by E. Hawthorn, L. P. Shortis, and J. E. Lloyd
Pumping studies on aqueous thoria slurries, by R. Murdoch and H. Kearsey
The use of hydrogen as a reactor coolant, by D. Bradlay.

CONTRIBUTORS TO THE JOURNAL

A. J. R. Belford, B.SC.—Assistant engineer, New Development Department, Stewarts and Lloyds, Corby.

Adam Belford was educated at George Heriot's School, Edinburgh. From 1940 to 1946 he was a draughtsman with the Ministry of Supply; he joined Munro and Miller Ltd of Edinburgh in the same capacity in 1946. In 1951 he moved to North British Rayon Ltd of Jedburgh as a development draughtsman, a position he held until 1956, when he took up his present post. Mr Belford obtained an external B.Sc. degree of London University in mathematics in 1954.

A. J. R. Belford

A. Brown

A. Brown, B.SC.—Research student, King's College, Newcastle-upon-Tyne.

Arthur Brown was born in 1936 at Hexham, Northumberland, and educated at Queen Elizabeth Grammar School. He then entered the Department of Metallurgy at King's College, Newcastle-upon-Tyne, graduating with first-class honours in 1957. He is at present taking a postgraduate course in metallurgy in the department, working on the alloys of zirconium.

C. A. Clark, B.SC., PH.D., A. INST. P.—Section leader, Development and Research Department Laboratories, The Mond Nickel Co. Ltd.

Dr Clark was educated at the City Grammar School and the University, Sheffield, where he obtained a special honours degree in physics. From 1950 to 1953 he carried out postgraduate research on the magnetothermal properties of ferrites in the physics department of the university, working under Professor W. Sucksmith, F.R.S. He joined The Mond Nickel Co. Ltd as a research physicist in 1953, and has been engaged on the development of alloys with improved magnetic properties. He was appointed to his present position in 1958.

C. A. Clark

P. E. Hardt

P. E. Hardt, DR.-ING.—Head of basic Bessemer plant, Klockner-Werke AG, Haspe Works, Hagen-Haspe, Western Germany.

Paul Hardt was born at Hilden, Rhineland, in 1908 and educated at the Technical University Aachen. After graduating he worked in the basic Bessemer plants of the August-Thyssen works at Duisburg-Hamborn and the Röchlingschen iron and steelworks. In 1930 he obtained his doctorate for a dissertation on the blowability of basic Bessemer pig iron. He was appointed to his present position in 1941.

G. T. F. Jay, B.SC. (ENG.) (MET), A.C.T., A.I.M.—Research metallurgy section, G.K.N. Group Research Laboratory, Wolverhampton.
Geoffrey Thomas Foster Jay was born in Birmingham in 1929 and educated at Wolverhampton Municipal Grammar School. In 1956 he obtained the external B.Sc.(Engineering) degree of London University after part-time study at the Wolverhampton and Staffordshire College of Technology and the Birmingham College of Technology. He joined the laboratories of Joseph Sankey and Sons Ltd in 1946, and transferred to the G.K.N. Group Research Laboratory in the following year. He has recently been engaged on research on silicon iron, the distortion of high-carbon high-chromium die steel, and the oxidation of mild-steel rod.

G. T. F. Jay

H. Kosmider

H. Kosmider, DR.-ING.—Works director and associate member of the board of Klöckner-Werke AG, Haspe Works, Hagen-Haspe, Western Germany.
Hans Kosmider was born at Rheinhausen in 1917 and studied at the Technical University of Berlin-Charlottenburg, where he obtained his doctorate with a dissertation on vacuum metallurgy. He joined the basic Bessemer plant of Klöckner-Werke AG in 1946, and in 1951 took charge of the metallurgical department; in 1953 he became head of the research department for the whole company. He was appointed to his present position in 1956.

H. Neuhaus, DR.-ING.—Chief metallurgist, Klöckner-Werke AG, Haspe Works, Hagen-Haspe, Western Germany.
Herbert Neuhaus was born in Dortmund in 1919 and educated at the Technical University of Berlin-Charlottenburg, where he graduated with a thesis on sulphide ores. He joined the metallurgical department of Klöckner-Werke AG in 1951, and was promoted chief metallurgist in 1956.

EDUCATION

Institute Prize at Sheffield

The Iron and Steel Institute Prize of ten guineas, awarded annually to the student reading for the degree of Bachelor of Metallurgy in the University of Sheffield who has reached the highest standard in production metallurgy, has been won this year by Mr H. K. Slater, of Billingham, Co. Durham.

Course on river pollution

A course on river pollution, sewage disposal, and trade waste treatment is being held at the University of Birmingham in 1960. Organized by the University's Department of Civil Engineering and Department of Extra-Mural Studies in cooperation with the Institute of Sewage Purification, the course lasts two weeks. The first, from 4 to 8 January, covers legal and biological aspects of pollution, hydraulics, and primary and secondary treatment methods. The second week, from 4 to 8 April, deals with equipment for sludge treatment, trade effluents, and the choice of treatment processes. The division of the course between two widely separated weeks has been made so as to cause less inconvenience to employers.

Enquiries about the course should be sent to Mr R. F. Wills, Civil Engineering Department, The University, Edgbaston, Birmingham 15.

Special courses at Kingston

Five special courses are being organized by Kingston Technical College for the 1959–1960 session that are of interest to metallurgists.

In the first term, there will be a course of eight lectures on Tuesday evenings, starting on 20 October, on the chemistry and metallurgy of rarer metals. There will also be a course on Thursday evenings, starting on 22 October, on the principles of corrosion and protection of metals.

There will be three courses, all of six lectures, during the second term: one on metallurgy and semi-conductor devices (starts 5 January), one on corrosion problems in the aircraft industry (starts 16 February), and the third on the technology of copper-base alloys (starts 18 February).

Full details may be obtained from the Department of Engineering, Kingston Technical College, Fassett Road, Kingston-upon-Thames.

FORTHCOMING CONFERENCES AND EXHIBITIONS

Aslib annual conference

The 34th Annual Conference of Aslib is being held at the Grand Hotel, Scarborough, from 5 to 7 October. Miss I. M. Slade, M.B.E., Information Officer of BISRA, is presenting a paper on the handling of technical information in industry, and Mr E. N. Simons of Edgar Allen and Co. Ltd, during what is described as 'a session in lighter vein', will be giving a talk entitled *An information officer goes to Moscow.*

Indian Institute of Metals

The 13th Annual Technical Meeting of the Indian Institute of Metals will be held in Bangalore from 1 to 5 December. The programme will include a symposium on structural changes in metals and alloys, arranged in collaboration with the Department of Metallurgy of the Indian Institute of Science. This symposium forms part of the golden jubilee celebrations of the Indian Institute of Science.

The 6th Metallographic Contest and Exhibition will be held during the meeting, which also includes works visits. The 8th Pandya Memorial Lecture is to be delivered by Dr S. Bhagavantam, director of the Indian Institute of Science.

US conference on flat-rolled products

The Mechanical Working Committee of the Iron and Steel Division of the Metallurgical Society of AIME is devoting its second conference to the subject of flat-rolled products. The conference is to be held in the Del Prado Hotel, Chicago, Ill., on 20 January 1960.

Papers will be presented on machine scarfing, selection of ingot sizes for the modern strip mill, scaling problems in hot strip rolling, residual stresses in cold-rolled and temper-rolled strip, roll and strip texture in cold-rolled strip, and processing and properties of magnetic materials. Chairman of the committee is Ralph D. Hindson of Hamilton, Ontario.

Engineering materials and design

An entirely new exhibition is to be held at Earl's Court, London, next year. The Engineering Materials and Design Exhibition, which will take place from 22 to 26 February 1960, will be devoted solely to materials and components in engineering design, including minerals, plastics, textiles, rubber, adhesives, refractories, ceramics, sintered products, timber, cement, metals, and alloys.

Associated with the exhibition will be a conference for engineering designers. Papers will be presented by leading experts on most of the materials covered by the exhibition.

Compressed air and hydraulics

The Empire Hall, Olympia, London, will be the home of the First International Compressed Air and Hydraulics Exhibition, from 25 to 29 April 1960. It is organized by *Compressed Air and Hydraulics*, the monthly technical journal.

Shaping and testing of sheet metal

The Société Française de Métallurgie and the International Deep Drawing Research Group (IDDRG) are organizing a colloquium on sheet-metal forming, with special emphasis on methods of testing.

The colloquium will be held in Paris from 23 to 25 May 1960. Provisionally, the programme will be divided up into the following sessions: theoretical studies of sheet-metal forming and the materials used in sheet forming, sheet-metal testing, and new techniques of sheet-metal forming.

Those wishing to present a paper to the colloquium should send the title and a brief summary to the Secretariat before 1 November. The completed or provisional texts of the papers selected for presentation will be required by 15 February. The papers should be in English, French, or German.

The Société Française de Métallurgie secretariat is at 25 rue de Clichy, Paris 9, and that of the IDDRG at the BISRA Laboratories, Hoyle Street, Sheffield 3 (Dr S. Garber).

Gas chromatography

The Society for Analytical Chemistry and the Gas Chromatography Discussion Group are joint organizers of the Third Symposium on Gas Chromatography, to be held in the Assembly Rooms, Edinburgh, from 8 to 10 June 1960. Further details may be obtained from L. Brealey Esq., Boots Pure Drug Co. Ltd, Standards Department, Station Street, Nottingham.

Powder metallurgy

The 1960 International Conference on Powder Metallurgy will be held in New York from 13 to 15 June; its purpose is to provide an evaluation of the present status of powder metallurgy and its part in modern advanced technology. One day will be devoted to each of the following: fundamentals and theory; technology and methods; alloys, materials, and applications. Papers are invited in all these subjects; those interested should send a 200-word summary to Dr C. G. Goetzel, New York University, Department of Engineering, University Heights, New York 53, N.Y., by not later than 15 October 1959.

NEWS OF SCIENCE AND INDUSTRY

Continuous casting

It was recently announced that The United Steel Companies Ltd had become shareholders in Concast AG of Zürich, together with the Schloemann Company of Düsseldorf and the Cie. des Forges et Aciéries de la Marine et de St Etienne of Paris. New board members include Mr G. N. F. Wingate, director and

general manager of the Distington Engineering Co. Ltd, a United Steel subsidiary, Dr G. Losch (Krefeld), Dr B. Knapp (Düsseldorf), and M Henri Malcor (Paris); the chairman is Mr Irving Rossi of New York.

Concast is the leading company in the field of the continuous casting of metals, and especially of steel. It is at present building two machines for casting wide slabs, one for Japan and the other for France. The company is also pioneering the development of horizontal continuous casting of steel; two machines have been built, and first tests seem to be very promising. This method of casting is already in commercial use for the production of non-ferrous billets.

Another Ajax at Scunthorpe

A second open-hearth furnace at the Appleby-Frodingham Steel Company has now been converted to use the Ajax oxygen process (*JISI*, 1958, Sept., 1–29). In its first week of operation it produced 912 tons more than its previous best for a full week.

The changeover to Ajax working takes four to eight weeks, depending on the mechanical handling facilities available and the structural soundness of the furnace. The capital cost of conversion is only a fraction of that required for installing any of the other oxygen processes.

Davy-United reorganization

As a result of the growth of the company, the board of the Davy and United Engineering Co. Ltd has proposed a new group organization, designed to effect some degree of decentralization.

The company previously trading as the Davy and United Engineering Co. Ltd becomes the holding company of the group, under the name of Davy-United Ltd. Two new subsidiaries have been formed; the first will retain the old name, and will carry on the main engineering activities of the group. It will comprise the Darnall Works at Sheffield (excluding the instrument shops), the Glasgow works in Bridgeton, and the construction division at Brantwood, Sheffield.

The second new subsidiary will be known as Davy and United Instruments Ltd; it will be responsible for the work formerly undertaken by the instrument division in the development and manufacture of electronic and radiation instruments for automatic control of rolling mills and other steelworks processes, industrial weighing, etc.

Manufacture of rolls and steel castings will continue to be carried out at Billingham, Co. Durham, by Davy and United Roll Foundry Ltd, another wholly owned subsidiary.

All-basic furnaces

Following a series of roof trials on tilting furnaces at Appleby-Frodingham, the success of the all-basic furnace has been so firmly established that the company has converted seven furnaces to this form of construction. The Spinella R2 basic brick developed by General Refractories Ltd has given a record roof life for this type of brick of 167 days, during which time over 70 000 tons of steel were produced.

Warren Spring Laboratory

The Rt Hon. Lord Hailsham, Q.C., Lord President of the Council, opened on 29 June the new Warren Spring Laboratory of the Department of Scientific and Industrial Research at Stevenage. The laboratory was set up, in the words of the Council for Scientific and Industrial Research, 'to carry out process research and development over a wide field not limited to particular areas of technology'.

The new station has taken over two programmes from the old Fuel Research Station, dealing with atmospheric pollution and the Fischer–Tropsch process. It is also working on mineral processing and chemical engineering problems. The director of the laboratory is Mr S. H. Clarke, C.B.E., M.SC.

Visit of Russian tinplate experts

Three leading Russian steel experts, specializing in tinplate, recently completed a 16-day tour of British tinplate works and laboratories. The party consisted fo Dr S. P. Antonov, deputy chief engineer of the Magnitogorsk Combinat, Mr D. I. Jasnikov, head of the tinplate department at the Zaporozahe Steelworks, and Mr V. A. Paramonov, head of the tinplate laboratories at the Central Institute for Ferrous Metallurgy, Moscow.

The group spent ten days in South Wales visiting the Port Talbot, Trostre, and Velindre works of The Steel Company of Wales Ltd and the Ebbw Vale works of Richard Thomas and Baldwins Ltd; a day was also spent at the BISRA Swansea laboratories. On their return to London, the group paid visits to the Tin Research Institute at Perivale, a factory of Crosse and Blackwell Ltd, and the BISRA Battersea laboratories.

The visit was arranged by BISRA as part of the series of interchange visits arranged between the Association and the Central Institute for Ferrous Metallurgy in Moscow. It is the second visit to be carried out, the first being made by the group of British continuous casting experts who visited Russia in April.

DIARY

11–13 Sept.—SYMPOSIUM ON CREEP-RESISTING MATERIALS—Marienbad, Czechoslovakia.

13–18 Sept.—YUGOSLAV ASSOCIATION FOR PROTECTION OF MATERIALS—Conference on protection against corrosion of structures and equipment of hydraulic systems and hydroelectric power plants—Belgrade.

17 Sept.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—Visit to Berkeley nuclear power station.

18 Sept.—INSTITUTE OF VITREOUS ENAMELLERS—Silver Jubilee Banquet—Park Lane Hotel, London W1, 7.30 for 8 pm.

21–29 Sept.—THE INSTITUTE OF METALS—Autumn Meeting—Sweden.

23–25 Sept.—ABRAHAM DARBY ANNIVERSARY MEETING—Birmingham and Coalbrookdale.

4–10 Oct.—INSTITUTO DEL HIERRO Y DEL ACERO—4th General Meeting—Madrid.

4–10 Oct.—26th INTERNATIONAL FOUNDRY CONGRESS—Madrid.

5–7 Oct.—ASSOCIATION OF SPECIAL LIBRARIES AND INFORMATION BUREAUX (ASLIB)—34th Annual Conference—Scarborough.

7 Oct.—BRITISH NUCLEAR ENERGY CONFERENCE—*Nuclear-powered dry cargo ships*, by E. C. B. Corlett and E. P. Hawthorne—Institution of Naval Architects, 10 Upper Belgrave Street, London SW1, 4.45 pm.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on page 386 of the August 1959 issue of the *Journal*:

1122 'Aerodynamic Design of the Open-hearth Furnace.' III–Functions of Lower Furnace. HASIMOTO, H. A. *Tetsu-to-Hagane*, 1957, Feb., pp. 117–121. (£8)

1146 'The Spectrographic Analysis of Basic Pig-iron and Steel by the Scanning Slit Method.' JONCKERS, M. D. E., and A. DANIELS. *Rev. Mét.*, 1958, July, pp. 601–612. (£5)

1147 'The Effect of Non-metallic Inclusions and Mo on the Mechanical Strength of 13% Cr Steel.' ONO, K., and R. SASAKI. *Tetsu to Hagane*, 1955, Dec., pp. 1258–1264. (£8 15*s* 0*d*)

1164 'The Rotor Process.' SPETZLER, E. *Neue Hütte*, 1958, Feb., pp. 85–93. (£5 5*s* 0*d*)

1167 'Final Analysis of Bath and Slag in the Basic Converter Process.' WEBER, F., *et al. Stahl u. Eisen*, 1958, 27 Nov., pp. 1734–1745. (£7)

1214 'Contribution to the Isolation of Sulphides in Steels.' KOCH, W., and E. ARTNER. *Arch. Eisenhütt.*, 1958, Dec., pp. 737–744. (£5 10*s* 0*d*)

1239 'Effect of Arsenic, Copper, Tin and Molybdenum on Impact Properties of Dead Soft Steel.' SAWAMURA, H., *et al. Tetsu-to-Hagane*, 1955, Jan., pp. 23–31. (£10)

1244 'The Use of Radioactive Isotopes for Determining the Origin of Non-metallic Inclusions in Steel.' SKUIN, K. *Technik* (Berlin), 1958, July, pp. 489–492. (£2 10*s*)

1264 'Contributions to the Physical Investigation of Fatigue Damage.' WEISZ, M. *Rev. Mét.*, 1959, Jan., pp. 83–103. (£8 15*s* 0*d*)

1273 'Transmission of Ultrasonic Vibrations in Metals.' ORS MARTINEZ, J. *Inst. Hierro Acero* (Madrid), 1958, Oct.–Dec., pp. 263–281. (£6 10*s* 0*d*)

1281 'Investigations on Pickling Baths.' PETZOLD, A. *Metalloberfläche*, 1955, Dec., pp. 205A–207A. (£2)

1291 'The Development of a Weldable Manganese-Titanium-Aluminium Alloyed Steel Quality St.52 in Hungary.' KRISTOF, G., *et al. Neue Hütte*, 1958, July, pp. 425–432. (£5 15*s* 0*d*)

1296 'Influence of the Annealing Time on the Structure and the Behaviour in Transformation of Plain Carbon Steels.' BORCHERS, H., and G. SAUR. *Stahl u. Eisen*, 1959, 19 Feb., pp. 210–215. (£4 15*s* 0*d*)

1306 'Conclusions drawn from Rolling Tests in a Four-stand Cold Rolling Mill for Wide Strip.' MÜLLER, H. G., and W. LUEG. *Stahl u. Eisen*, 1959, 19 Mar., pp. 325–331. (£5)

1309 'Comparative Investigation of Defects in Heavy Forgings by means of Ultrasonic Waves and the Betatron.' BRAND, L. *Stahl u. Eisen*, 1959, 8 Jan., pp. 32–36. (£3 10*s* 0*d*)

1312 'Experience with a 15-MeV-Betatron used for the Non-destructive Testing of Steel Products.' KRÄCHTER, H. *Stahl u. Eisen*, 1959, 2 Apr., pp. 419–426. (£5)

1313 'Critical Consideration of Mechanization and Automation in Steel Production.' HÜSER, K. H. *Stahl u. Eisen*, 1959, 22 Jan., pp. 65–73. (£6 10*s* 0*d*)

1317 'The Various Effects of Vacuum Melting on the Gas Content of Metals.' PFEIFFER, I. *Z. Metallk.*, 1958, Sept., pp. 455–460. (£2 10*s* 0*d*)

1329 'Hot Rolling of Thick Steel Plate (up to 40 mm) Clad on One side with Stainless Steel.' ZIDEK, M., and B. GLATZ. *Hutnické Listy*, 1958, Aug., pp. 679–687. (£7)

1330 'The Microstructure of Cast High-speed Steel.' YUSHKEVICH, P. M., and S. A. FEDEROVA. *Metallov. Obra. Met.*, 1955, (3), pp. 21–25. (£2)

1348 'Consideration of the Precision of Vickers and Rockwell Hardness Tests.' ROSSOW, E. *Mét. Corr. Ind.*, 1955, Dec., pp. 476–483. (£4 10*s* 0*d*)

1350 'Steels for Tubular Structures.' BORN, K. *Tech. Mitt.*, 1959, Mar., pp. 109–113. (£4)

1363 'Standardization of Heating Practice and Control in a Coke Oven Battery.' MOSYAKOV, G. V. *Koks i Khimiya*, 1958, (7), pp. 26–29. (£3 5*s* 0*d*)

1364 'Preventing the Occurrence of Premature Cavitation in the Piercing of High-alloy Steels.' PLYATSKOVSKII, O. A., and G. P. PISHCHIKOV. *Stal*, 1952, Apr., pp. 330–336. (£5 10*s* 0*d*)

1365 'Continuous Ultrasonic Testing of Products of the Iron and Steel Industry.' KOPINECK, H.-J., *et al. Stahl u. Eisen*, 1959, 28 May, pp. 786–797. (£7 5*s* 0*d*)

1370 'Interaction between Steel and Moulding Material.' TROMMER, W. *Giesserei*, 1955, 18 Aug., pp. 433–440. (£6 5*s* 0*d*)

ABSTRACTS OF CURRENT LITERATURE *Iron and Steel Manufacture and Related Subjects* AND BOOK NOTICES

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MINERAL RESOURCES

How to estimate ore reserves H. J. Wolf (*Eng. Min. J.*, 1958, **159,** Dec., 92–95) Use of drill-hole data is briefly considered and a system of mining is proposed.

Phenomena of the siderite metasomatosis E. Raguin (*Berg.-Hutten. Monatsh.*, 1958, **103,** Dec., 240–244) A description of the general characteristics of metasomatosis is followed by an account of the differences between the two main types of siderite metasomatosis, with reference to some examples.

The geology of Cockatoo Island, Yampi Sound, Western Australia I. W. Reid (*Austral. Inst. Min. Met., Stillwell Anniversary Volume*, 1958, Dec., 213–239) A haematite orebody is present Its origin is discussed.

Thoughts on the problem of the age of the spathic iron ores in the Pyrenees and the Eastern Alps G. Guitard (*Berg.-Hutten. Monatsh.*, 1958, **103,** Dec., 251–254)

Manganese and chrome ore outlook J. M. Warde and E. P. Burke (*J. Metals*, 1958, **10,** Dec., 790–795) The known reserves of Mn and Cr ores, the probable demand and the supply position up to 1970, and the estimated effect of USSR production and exports on the world market are discussed.

On lead, zinc, and molybdenum ore deposits in Mezica, Yugoslavia S. Grafenauer (*Rud. Met. Sbornik*, (3), 263–294) [In Serbo-Croat] A mineralogical and chemical analysis is given. A detailed abstract in German is appended.

ORES—MINING AND TREATMENT

The costing of iron ores. G. Winkler (*Neue Hutte*, 1959, **4,** March, 148–151) A method of drawing up a price list for iron ores is reported that satisfies the technical and economic requirements of a socialist production system. It is based on average ore values and takes average metallurgical processing conditions into account.—L. J. L.

Advances in magnetic separation of ores L. A. Roe (*Min. Eng.*, 1958, **10,** Dec., 1261–1265) Recent success in new designs of dry magnetic separation machines points to the impending production of higher-quality iron ore. The dry process is outlined and the modifications necessary for local conditions indicated. The features of a number of plants in America and Europe are mentioned.—T. G.

Magnetic separation for Mesabi magnetite taconite J. E. Forcica, L. G. Hendrickson, and O. E. Palasvirta. (*Min. Eng.*, 1958, **10,** Dec., 1269–1276) All pilot and commercial plants working with Mesabi Range taconite employ wet separation. The magnetic separation data from operating plants are compiled in a table, and the high efficiency of separation is discussed. Separator design is described, features affecting operation and maintenance are pointed out, and separator performance is dealt with at length.—T. G.

Pilot plant for jaspilite ore beneficiation S. G. Salamy (*BHP Techn. Bull.*, 1958, **2,** Sept., 2; *Chem. Eng. Min. Rev.*, 1958, **51,** Dec. 15, 47–48) A test programme is described for the beneficiation of the low-grade iron ore deposits of jaspilite in South Australia. The deposit is a mixture of hematite and silica. The plant at Whyalla is briefly described.

Nickel-cobalt separation at Sherritt Gordon V. N. Mackiw, W. C. Lin, R. L. Benoit, and T. W. Benz (*J. Metals*, 1958, **10,** Dec., 800–802) The techniques described for the treatment of a Ni–Cu–Co concentrate in a leaching operation at the Sherritt Gordon Ni refinery can be applied with minor modifications to a wide range of solutions containing Ni and Co.

How high tension electrostatic separation recovers iron ore R. E. Barthelemy (*Eng. Min. J.*, 1958, **159,** Dec., 87–91) A general review of principles, and applications to haematite and martite with figures for recoveries and accounts of ores from different sources.

Studies on the oxidation of pyrite. Part 1: Thermal decomposition of pyrite A. Nishihara and Y. Kondo (*Merm. Fac. Eng. Kyoto Univ.*, 1958, **20,** Oct., 285–306) [In English] The kinetics of decompositions were studied and a break in the curve at a mol. fraction of 0·3 is found with an activation energy of 50·9 Cal below and 40·3 Cal above. A range of non-stoiochiometric iron sulphides are found, some ferromagnetic, some antiferromagnetic and some paramagnetic (in the range FeS–$FeS_{1\cdot13}$). The two latter are unchanged *in vacuo* at 300°C but change to ferromagnetics in air or to a low vacuum on heating; these appear to be near the limit of solubility of S in $FeS_{1\cdot13}$.

Part 2: Kinetics of oxidation of pyrite. (307–335) Atmospheres of O_2, SO_2+N_2 were used. At 700–900°C a change in the direction of the curve was observed in thermobalance studies, more obvious at lower O_2 concentrations. The reaction occured by thermal decomposition followed by oxidation of the product. A rate constant proportional to the O_2 pressure was found. The activation energy was constant at ~8·3 Cal. At 550–650° decomposition is slow and three simultaneous reactions appear to occur for which the kinetics were formulated on various assumptions. Another scheme is suggested for ~800°C.

The provision of ore handling facilities at General Terminus Quay, Glasgow G. Gray and A. Young (*Trans. Inst. Eng. Ship. Scotland*, 1957–58, **101,** 428–463)

Pelletisation of fine iron ore concentrates. A. Stoian and M. Sirbu (*Met. Const. Masini*, 1958, (11), 942–946) [In Rumanian.] The article deals with determining the optimum conditions for making use of 'cold' agglomeration, i.e. pelletisation in which the fine material is transformed into small spheres by mechanical rolling, which can later be hardened either by heating or in the classical way. Many parameters have been studied such as the influence of humidity, additions, rate of rolling, slope of the apparatus, rate of feed, etc.

Trial production of iron-coke J. A. Gregory and F. G. Hubbard (*BHP Techn. Bull.*, 1958, **2,** Sept., 29–33) A full-scale coke-ovens and blast-furnace trial carried out at the BHP Newcastle works is described, and the results assessed. Due to the prevailing weather conditions and the curtailment of the trial, results could not be considered conclusive.

Research on the production of iron-coke I. Lazarev and O. Havel (*Paliva*, 1958, **38,** (8), 265–269) [In Czech] Laboratory and full-scale works tests showed that up to 20% of iron ore admixtures in coking are permissible without significantly affecting the coking quality of the coal. The iron-coke obtained was stronger than ordinary coke, and coke yields increased by about 13% over those of plain coke without significant losses in chemical by-products. Technological details of the experiments, including those carried out in coke-ovens in the works, are given.—P. P.

Continuous limestone burning for the sinter mix G. G. Oreshkin, N. Z. Plotkin, and A. K. Rudkov (*Stal'*, 1959, (3), 196–203) A circular furnace is described with a revolving grate for continuous operation.—R. S.

Electric system continuously weighs and proportions materials in Jones and Laughlin's new sintering plant (*Ind. Heat.*, 1958, **25,** Sept.,

1740–1744) The feed control system at Jones and Laughlin's 2500 ton per day sinter plant at Cleveland is described. The proportional flow rates of the various materials are controlled and the ratio may be varied by the operator.—A. G.

Studies on self-fluxing sinter K. Sanbongi and N. Nishida (*Tetsu to Hagane*, 1958, **44,** Aug., 853–858) Using Zungun ore, sinter studies were made on a Greenawalt-type machine. The beneficial effects of lime, limestone and $Ca(OH)_2$ increased up to 4%, and finer sizes were better. Moderate moisture contents gave sufficient strength. OH slag produced a great increase in sinter strength. Reducibility was increased by all additives except slag. Strength and reducibility depend on the composition and nature of the matrix.—K. E. J.

On the mechanism of iron oxide sintering B. Dobovišek and N. Smajic (*Rud. Met. Sbornik*, 1958, (3), 241–260). [In Serbocroat] Shrinkage of compacts consisting of Fe_2O_3, and of Fe_2O_3 with either 10% SiO_2 or 5% $CaCO_3$ and natural limonite ore was studied. It was found to obey in all cases the theoretical relations proposed by Kuczynski. A detailed English abstract is given.—P. F.

Advantages arising from the use of sinter of high basicity L. Brož (*Hutnik*, 1958, **8,** (8), 257–260) [In Czech] It is shown that high-basicity sinters are used advantageously with lean ores to increase the efficiency of pig-iron production. Suitable methods of increasing the sinter basicity by the addition of finely-ground lime of definite granulometry are indicated.—P. F.

Agglomeration and sintering plants used in ore preparation in Malmberget in Sweden J. Formánek (*Hutník*, 1958, **8,** (8), 280–282 [In Czech] A highly laudatory report is given of the performance and integration of the Swedish plant.—P. F.

The kinetics of the reduction of iron oxides by carbon monoxide Van Sao-Tsin and V. V. Kondakov (*Acta Met. Sinica*, 1958, (3), 197–209) The experiments were conducted at temperatures between 900° and 1100° with a volume rate of gas reduction of 0·25, 0·35, 0·50 and 1 l/min. They showed that under these conditions with an average grain size between 0·5 and 4 mm and a volume rate between 0·25 and 1 l/min the reduction reaction proceeds with measurable kinetics. The analytical treatment of the experimental data has shown that the reduction of the ferrous oxide by CO is a reaction of the first order and the relation between the reaction constant and temperature is given. On this basis the activation energy of the reduction of the ferrous oxide by CO is 18·85 Kcal per mole.

Reduction of Rumanian siderite and limonite iron ores M. Ispas (*Studii si Cercetari de Metalurgie*, 1956, (1), 65–74) [In Rumanian] A method is described by which it is possible to observe continuously the reduction process with time. At low temperatures the roasting of the ores exerts a strong influence on the reduction reaction but at high temperatures (750–850°) its influence is smaller. At 650° the roasted ore is more difficult to reduce than the natural ores. Siderite begins to decompose at 390° and decomposition becomes intense between 550–600°. Increasing the temperature speeds up the rate of reduction. Any exceptions are explained by the sintering occurring at high temperatures. At 850° slight sintering occurred. Natural siderite is reduced more rapidly than limonite from the B layer, but roasted limonite reduces more easily.

Reductibility of Palazu Mare iron ore in a methane atmosphere. M. Ispas (*Studii si Cercetari de Metalurgie*, 1958, (3), 307–318) [In Rumanian] The chemical composition of the Raw Palazu Mare iron ore is 20·9% Fe, 0·116% P, 0·1% S, 3·65% CaO, 4·7% MgO, 49·8% SiO_2, 4·482% Al_2O_3 and other elements 2·87%. With a modified basicity in a methane atmosphere it was found that the reducibility of the ore is low, that an increase in basicity does not improve it, but on the contrary results were worse than with the raw ore. It was also shown that methane can be used for easily reducible ores. This ore can only be used after roasting, when the Fe_3O_4 passes into Fe_2O_3.

FUEL—PREPARATION, PROPERTIES AND USES

Cleaning of coal for the industries G. G. Sarkar and S. K. Mitra (*Iron Steel Rev.*, 1958, **2,** Nov., 471–478) A general account of the processes used in India.

Sampling coal A. E. Williams (*Elect. Times*, 1958, **134,** Dec. 25, 699–971) The method used at U.S. power stations is described.

Tata's last coke oven battery lit up (*Iron Steel Rev.*, 1958, **2,** Nov. 479–480).

The carbonisation of coal in coke ovens G. W. Lee (*Coke Gas*, 1958, Sept. 368–372, 381; Oct., 419–425; Nov., 472–474; Dec. 524–529) U.K. statistics and the sampling, analysis and testing of coke are given. Blending and the mechanism of coke formation are considered. Quality assessment is then reviewed. Coke quality as correlated with blast furnace and cupola performance is then discussed. The work of the British Coke Research Association is outlined.

Smokeless charging of coke-ovens M. Sedlacek (*Hutnik*, 1958, **8,** (9), 311–313). [In Czech] Experiences with the removal of smoke by means of a suction device operating with steam injection are described.—P. F.

The effect of coking technology on coke quality J. Kunc and J. Holub (*Paliva*, 1958, **38,** (12), 405–409 [In Czech] Experiments on the effect of moisture content on the quality of coke derived from various types of coking coals are described. No effect was found with moisture contents ranging from 8 to 13%. Maintenance of constant moisture content is shown to be desirable; with a lowering of moisture content, improvements in the coking rates can be expected in certain cases. Potential improvements arising from this have not so far been taken advantage of adequately in Czechoslovakia.—P. F.

On the assessment of coking-coal quality V. Beneš (*Paliva*, 1958, **38,** (9), 302–307) [In Czech] On the basis of experiments with many types of coking coals it is shown that the frequent failure of the swelling test to give a cokability index related to the strength of the coke, as given by the Micum test, is due to the failure to take into account the dilatation of the coal on coking as an index of cokability. On utilising the information provided by dilatometric curves, in addition to the swelling index, a direct relation between cokability of the coal, and the strength of coke is found. I the case of coal mixtures containing non-coking components, dilatometry does not, however, provide an aid to the estimation of coke strength.—P. F.

Solving waste problems of a large chemical type coke plant by cooperative efforts P. S. Savage (*Blast Furn. Steel Plant*, 1958, **46,** July, 705–710) Work carried out at the plant of the Donner-Hanna Coke Corporation, Buffalo, U.S.A. to minimize water pollution is described.—B. G. B.

On the high-temperature mechanical properties of coke used in the steel industry P. A. Shchukin (*Paliva*, 1958, **38,** (9), 299–301) [In Czech] On the basis of experiments it is shown that the abrasion resistance of coke is increased by heating to 1200°C either in the blast-furnace or outside it, but that by heating coke lumps to 1300°C the compression strength decreases. It was established that a relation exists between the hot and cold strength of coke, both increasing together. The cold-strength can therefore be utilized for assessing the behaviour of the coke at high temperatures in the blast-furnace.—P. F.

Burning of liquid fuels J. M. Schenström and R. Collin (*Jernkont. Ann.*, 1958, **142,** (12), 739–783) Work on burner processes and flame velocity, emissivity and soot formation at the International Flame Research Foundation is reported.

Carbon: The key to metallurgy (Sir) C. Goodeve (*BCURA Quart. Gazz.*, 1958, (36), 1–11) The 7th Coal Science Lecture. The general physico-chemical principles and redox conditions of metallurgical processes are outlined, with special reference to reduction by carbon. Much thermochemical data are shown.

International methods of sampling and analysis of solid fuels—2 J. G. King (*Coke Gas*, 1958, **20,** Dec., 509–513) The ISO Harrogate meeting decisions are reviewed.

Oxygen lamp for determination of sulphur in fuel gas D. McA. Mason and C. E. Hummel (*Anal. Chem.*, 1958, **30,** Nov., 1885–1886)

AIR POLLUTION AND SMOKE

Problems of air pollution in Germany H. Lent (*J. Inst. Fuel, preprint*, 1959, p.7)

Notes on the US national conference on air Pollution, Sheraton-Park Hotel, Washington, Nov. 1958 (*BCSO (NA) Report No.*1151, 1958, Dec. 8, pp.12) Abstracts of the papers are given. The steel industry was dealt with by M. D. Howell and the difficulties met with at present are noted.

The air pollution situation today, with special references to control legislation A. D. Brandt (*Iron Steel Eng.*, 1959, **36,** Jan., 103–108) The nature of air pollution and the main sources of contamination in the steel industry are discussed, and suggested lines on which regulations should be framed with regard to the problems to be solved are outlined. The present state of air pollution control legislation in the United States is surveyed.

Sampling of dust and fume (*Iron Steel*, 1958, **31,** Nov., 544–545) A description is given of the LISA dust-sampling equipment – a commercial version of the type developed by BISRA. Although mainly intended for use on chimney stacks, it can also be used as an aid to process control.

Collection of gas-borne dust particles by means of an aspirated sampling nozzle S. Badzioch (*Brit. J. Appl. Phys.*, 1959, **10,** Jan., 26–32) Work by BCURA is reported. Theoretical and experimental studies of collection efficiency are made and it is shown to depend upon the ratio of velocity of aspiration to velocity of the undisturbed stream and on the ratio of the length representing upstream disturbance to the range of the particle, which is the distance it would travel in still gas if projected at the stream velocity. The upstream disturbance length is a function of nozzle diameter.

Gas cleaning in practice W. T. Cosby (*J. Jun. Inst. Eng.*, 1959, **69,** Jan., 113–125) A review of dust removing equipment is given with special reference to selection for various purposes. A table including many metallurgical processes is given.

Emissions from ironfoundries F. M. Shaw (*Fuel Econ. Rev.*, 1959, **37,** 41–49) Smoke, grit and dust emission and measures and installations for their control are reviewed.

Static automatic control for electrical precipitators L. L. Little (*Blast Furn. Steel Plant*, 1958, **46,** July, 711–713) A new control system for regulating the input power for electrostatic precipitators is described. It is particularly suitable when the size of particle or concentration change rapidly or change over a wide range.—B. G. B.

Cleaning iron oxide fumes with a bag filter K. H. Sargent (*Iron Coal Trades Rev.*, 1959, **178,** Jan. 9, 79–85) An account of pilot-scale tests by British Oxygen is given. Uses of bag filters are reviewed and bag life, pressure drop and efficiency are considered. The theory of pressure drop is developed into a formula suitable for use in design. The efficiency of the pilot installation is then considered and future prospects are outlined (20 refs.)

TEMPERATURE MEASUREMENT AND CONTROL

The care of platinum thermocouples H. E. Bennett (*Wild-Barfield J.*, 1958, **6,** Dec., 2–5) Factors impairing the accuracy and working life of Pt thermocouples are discussed. These include prolonged heating, stresses and contamination by metallic vapours or grease.

An improved radiation pyrometer H. Fachse (*VDI–Z*, 1959, **101,** Feb., 124–127) An abstract of a report by F. Lieneweg and A. Schaller 'Verbesserung der Messeigenschaften des Ardometer' (*Siemens-Z*, 1958, **32,** 331–335). The advantages of radiation pyrometers are discussed, and a description of the features of the Ardometer is given, with a sectional diagram of the instrument.

Practical aspects of radiation pyrometry T. Land (*Trans. Soc. Instr. Techn.*, 1959, **11,** Mar., 10–18) Choice and use of radiation pyrometers are explained. Tables of emissivity and

corrections for various types of pyrometer are given.

Radiation pyrometer for foundry measurements Land Pyrometers Ltd (*Engineer*, 1959, **207**, Jan. 30, 189) A photocell instrument is described. It can be mounted to measure pouring temperatures from cupolas or holding furnaces over the ranges 1200–1500°C or 1300–1600°C.

Immersion thermocouple practice H. V. Schubert (*Iron Steel Eng.*, 1959, **36**, Jan., 91–97) The design, construction, operation and maintenance of the immersion thermocouple are described and discussed.

Continuous temperature measurement of liquid steel in the ladle P. Ya. Sorokin, A. V. Zabaikin, P. P. Babich, and O. A. Zakharov (*Zavods. Lab.*, 1958, (12), 1475–1477) A protecting cover round a thermocouple is described which makes it possible to mount it in the ladle and so check the temperature during pouring. It consists mainly of a hollow cylinder of zirconium oxide or fused magnesite. Comparison of temperature readings obtained continuously by immersion thermocouple and by optical measurements show the reliability of the first-named method.

REFRACTORY MATERIALS

Development of a foamed alumina castable cement W. F. Zimmerman (*Ind. Heat.*, 1958, **25**, Nov., 2330–2334) The process of foaming a basic refractory material such as Al_2O_3 is described and the advantages of such a product are given.—A. G.

Magnesia from sea water (*Metallurgia*, 1958, **58**, Nov., 225–227; *Iron Steel*, 1958, **31**, Nov., 520–522) An account of the development and present position of the production from sea water by the Steetley Company at Hartlepool of magnesia for refractories.

Study of the $3CaO,SiO_2$ in dolomite refractories (2) G. Yamaguchi and S. Komatsu (*Tokyo Univ. Ann. Rep. Eng. Res. Inst.*, 1958, **17**, Sept., 45–48)

Radioactive tracer techniques in refractories research D. H. Houseman (*Refract. J.*, 1958, **34**, Dec., 540–548) After describing the sources and properties of radioactive isotopes some examples of their application in the steel industry are given. These include the use of encapsulated sources to determine refractory wear and the addition of isotopes to open-hearth slag and ladle lining to determine the source non-metallic inclusions in steel. A discussions of these techniques is appended.—A.G.

Some general considerations on thermal shock J. White (*Trans. Brit. Ceram. Soc.*, 1958, **57**, Oct., 591–623) The factors governing the thermal shock-resistance of brittle materials are discussed. The causes and importance of the thermal stresses set up during slow heating and cooling are considered in relation to mechanical strength.—A. G.

A sonic spalling test J. F. Clements and W. R. Davis (*Trans. Brit. Ceram. Soc.*, 1958, **57**, Oct., 624–644) A spalling test is described in which a test-piece is vibrated at its resonant frequency while being heated. Cracking is indicated by sudden changes in frequency.—A. G.

Transient thermal stresses promoted by the rapid heating and cooling of brittle circular cylinders E. Glenny and M. G. Royston (*Trans. Brit. Ceram. Soc.*, 1958, **57**, 645–677) The theory for calculating transient thermal stresses in brittle circular cylinders has been checked experimentally using a high-Al_2O_3 ceramic. Agreement is considered reasonable.

Some observations and reservations on thermal shock theory M. G. Royston and L. R. Barrett (*Trans. Brit. Ceram. Soc.*, 1958, **57**, Oct., 678–685) It is suggested that mechanical strength should be measured at the same rate of loading as occurs in thermal stressing to assess liability to crack. The strength of inhomogeneous bodies and 'tricks' to improve thermal shock-resistance are also discussed.

The coefficient of linear thermal expansion of chamotte and silica bricks Z. Engelthaler and K. Engelthaler (*Silikáty*, 1958, **2**, (3), 227–238) [In Czech] The coefficient of linear thermal expansion of several refractory brick materials used in Czechoslovakia were determined up to 1500°C. The effect of the mullite content on the coefficient of expansion, as well as the differences in the expansion of crystobalitic and tridymitic silica were measured.—P. F.

Testing the resistance to shock and abrasion of refractory products (Jourdain Apparatus-CGCF) J. Baron (*Centre Doc. Sidér. Circ.*, 1959, (1), 175–176) A note of the sampling and testing of refractories by this method.

The volume coefficient of thermal expansion of chamotte and silica products Z. Engelthaler and K. Engelthaler (*Silikáty*, 1958, **2**, (3), 239–242) [In Czech] On the basis of measurements in the range 20–1500°C it is shown that the materials expand as if they were isotropic; the volume coefficient of thermal expansion may therefore be taken to be equal to three times the linear coefficient at any given temperature.—P. F.

An instrument for measuring the thermal conductivity of sintered refractories at elevated temperatures S. Procházka and J. Hlavác (*Silicáty*, 1958, **2**, (3), 290–295) [In Czech] A modified sandwiched-plate method for measurement of the thermal conductivity of samples of $\sim$ 0·2 in. thickness and 1½ in. diameter in the range 200–500°C is described. The instrument is comparatively simple; the accuracy of measurement lies within $\pm$ 10%

Texture of refractories L. Lécrivain (*Trans. Brit. Ceram. Soc.*, 1958, **57**, Nov., 687–708) Total porosity and permeability are insufficient to enable the behaviour of refractories to be understood. Determinations of pore dimensions and distributions have been made by several methods. Apparatus is described and the significance discussed. Applications to aluminosilicate casting-pit refractories are considered. An ultrasonic method for the study of larger voids is also described.

Problems arising from the use of rammed sand for lining steelwork ladles M. Thiault (*Centre Doc. Sidér. Circ.*, 1959, (1), 157–168) An account is given of the use of fourteen types of sand containing varying amounts of alumina for the manufacture of monolithic ladle linings for basic Bessemer and OH plants. Composition of materials used, manufacturing techniques in various plants and the results obtained are described.

Trials of rammed sands. Practical use of the sands Poulain (*Centre Doc. Sidér. Circ.*, 1959, (1), 169–1747) Results obtained with various acid monolithic ladle linings are given, and economic factors are considered. It is concluded that substantial economies are possible compared with the use of brick.

IRON AND STEEL, GENERAL

Recent trends in the Lorraine iron and steel industry J. E. Martin (*Geography*, 1958, July, 191–199, reprint) A general account of mainly economic factors is given.

The Spanish iron and steel industry and its present-day expansion C. S. Vecinó (*Met. Elect.*, 1959, **23**, Jan., 202–205, 207–208) A review is given of the annual production of iron from 1943–1958, the production of electrical energy and coal during this period, and an analysis is given of the figures for ferroalloys, cast iron and ingot steel in more recent years, and of rolled material. The data are discussed in terms of Spanish iron and steelmaking capacity and prospects.

The national iron and steel industry J. Serrano (*Met. Elect.*, 1959, **23**, Jan., 214–215, 217–218) The distribution of steel products among various consumers is analysed and related to the Spanish economy; and the estimated requirements up to 1962 are outlined.

The future of the Italian steel industry J. Cairncross (*Banca Nazionale del Lavoro, Quart. Review*, 1957, Sept., 352–368) The prospects are considered up to 1960 in the light of experience of membership of the ECSC.

Problems of the development of the steel industry in perspective L. Kistelski (*Prz. Techn.*, 1958, **79**, March, 161–165) The production of steel in Poland has increased nearly five times from 1·2 mil t in 1938 to 5·7 mil t in 1957. The author argues that the production should and can be increased by 1970 to 12·5 mil t.

The development of the iron and steel industry in the USSR W. Katyszew (*Prz. Techn.*, 1957, **78**, Nov., 828–830) A brief survey of the development of the iron and steel industry in the last forty years is given. The progress is summarized in two tables. The production of steel has increased from 4,200,000 t in 1913 to 51,500,000 t in 1957.

The Japanese iron and steel industry (*Met. Bull.*, 1959, special issue, March) **The raw materials position** (15–17) **History and expansion of the steel industry** (18–23) with map **The steel industry as an exporter** (25–27) Statistical **The galvanized sheet industry** (29–30) **Progress in tinplate** (33) **Japanese iron and steel producers** (35, 37, 39) Tables showing products.

Automatic control of production processes in the Soviet iron and steel industry A. V. Leskov (*Metallurg*, 1959, (1), 4–6) Mechanized automated blast and OH furnaces produce 90% of Soviet pig iron and steel, but remote control and telemetering are still in the planning and testing stages. Automation has given an 8–10% increase of production and, in rolling mills, 15%. It is calculated that another 10^8 t can be obtained without new plant. Costs have been lowered 20% and labour by 25%. The problems of blast furnace control are being studied at four institutes, the use of oxygen and steel melting control also present problems and computers are already built. Heat flow control at Magnitegorsk is based on pre-heat rate in the checkers. The project of a 'thinking' OH furnace has been developed and tests have been carried out on No.1 furnace at Zaporozhstal. Automatic control of converter plants also requires study. All converters will use O_2 and automatic control of the O_2 must be related to the converter reactions. Punched card methods for blooming mills are being developed.—R. S.

Development and aims of water economy in the iron and steel industry K. H. Koch (*Stahl Eisen*, 1959, **79**, Jan. 22, 89–94) The author reviews plant and equipment as well as aims and aspects of water economy of the German iron and steel industry. Lack of water and pollution of rivers require the re-use of water. The principles of purification and aeration plants are described.—T. G.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

No. 2 blast furnace of the 'Empresa Nacional Sidérurgica', SA (*Met. Elect.*, 1959, **23**, Jan., 210–211) Characteristic data are given for the No. 2 blast furnace recently put into operation at Aviles.

The reconstruction of Kokura No. 2 blast furnace and its blowing-in K. Kasai, I. Okawa, and Y. Imao (*Sumi. Met.*, 1958, **10**, July, 186–206) [In Japanese, with tables and captions to illustrations in English.]

Reconstruction of hearth and hearth bottom of a blast furnace at the Dzershinsk plant G. G. Oreshkin and B. A. Brilliantov (*Stal'*, 1959, (3), 206–208) A carbon hearth with underbottom cooling of a new design was used. Inside and outside surfaces are shaped as spherical segments. Heat conductivity is the same in all directions. Plans are shown.—R. S.

Organization of work in rebuilding and repairing blast furnaces I. D. Vikhrev (*Metallurg*, 1958, (12), 6–9) A method of moving old furnaces out of the way to erect new ones is described which cuts down rebuilding time from 80–90 to 40–45 days. Safety and labour conditions are improved. Equipment is shown and the reconstruction of stoves and dust catchers is included.—R. S.

Rationalizing the charging of blast furnace materials V. A. Sorokin (*Stal'*, 1959, (1), 15) Many theses have been written on the subject by students of the Ural Polytechnik and the Don Industrial Institute. With furnaces working on hot self-fluxing sinter where fines up to 5 mm size require sieving off, the bunkers must be above the skip. A diagram of a suggested system is given.—R. S.

Operation of the blast furnace with block charging M. A. Sukonnik (*Metallurg*, 1958, (11), 9–12) Following the article *ibid.*, 1958, (5), by V. E. Levchenko, several blast-furnace men here comment on their own experience. Examples are given of the size of sinter used and the importance of chemical composition of the ore is stressed. Details of the ore used are given.—R. S.

Air cooling of blast furnace hearth bottoms N. V. Krepyshev (*Metallurg*, 1958, (11), 3–9) The author refers to the fact that the temperature of the concrete in the upper part of the foundations of the Kuznetsk blast furnaces reaches 1000 to 1100°C. Increasing the hearth thickness up to 0·7 to 0·8 of the diameter of the hearth had little effect as regards iron break-outs. It soon became evident that the hearth would have to be cooled from below. At the beginning of 1953, during major repairs to the hearth bottom, radioactive isotopes were inserted and the radioactivity of the iron tapped gave an indication of hearth bottom wear. The cause of break-outs was found to be not so much the formation of deep holes in the hearth bottom as the presence of cracks which penetrated the foundations. Angular coolers were inserted beneath the hearth bottom. Steel corseting was used to strengthen the foundations and steel strapping was used to increase heat evacuation from the lower part of the hearth bottom. Air cooling below the hearth considerably reduced the temperature of the lower part of the hearth bottom and of the foundations.—R. S.

A discussion regarding the profiles of small Chinese blast furnaces Shi Nai Sin (*Gangtie*, 1958, (2), 23–29; from *Ref. Zhur. Met.*, 1959, (1), 294) Dimensions for furnaces of capacities of 200 and 500 m^3 are given.—R. S.

The rationalization of the design of blast furnace hearths B. N. Zherebin and N. V. Krepyshev (*Stal'*, 1959, (1), 10–14) The cooling and construction of the hearth bottoms is described. Air cooling beneath the hearth produced more uniform temperatures in the lower part of the hearth and in the foundation. The use of carburized chamotte bricks is not to be recommended as they are not stable enough.

Apparatus for feeding coke breeze or pulverized coal into blast furnaces M. Lenartowicz, M. Kowalewski, and L. Muller (*Polish Patent* 37887, 10 Oct. 1955; from *Ref. Zhur. Met.*, 1959, (1), 318) An intermediate feeder is combined with a nozzle feed tube. This is placed at the level of the throat platform and can be charged by the normal skip, the nozzle is directly underneath. Continuous working is secured by a system of conical traps opening alternately.—R. S.

Comparison of three methods of shutting down of blast furnaces with a view to the rapid repair of the shaft V. Etorre (*Centre Doc. Sidér. Circ.*, 1959, (1), 135–155) The principles underlying the three methods are outlined, and a detailed account of the application of the techniques to four types of blast furnace is given.

The results of blast furnace operation for foundry pig iron on an all-sinter burden T. Kanamaru (*Tetsu to Hagane*, 1958, **44,** July, 800–807) Practice at the Amagasaki Iron and Steel Mfg Co. is based on large amounts of home ore; pyrites cinder and Kanchira ore are sintered after treatment for extracting copper. The copper contents limit practice to 50–70% sinter for basic iron, and 80–100% sinter for foundry iron. The high-sinter burdens showed good reducibility and efficient desulphurization, and no control difficulties were found with 100% sinter burdens.—K. E. J.

Modernization of power and blast generating plants in four integrated iron and steel works (*Stahl Eisen*, 1959, **79,** Feb. 19, 185–187) Introduction to the following symposium on power and blast-generating plants, and a statistical review. **The change-over in power generation from gas engines and low-tension steam to a power station with 64-MW steam turbines working at 115 Atm** W. Wittwer (187–191) The new power station requires 2600 k.cal/kWh. as compared with the 4000 k.cal/kWh. of the old one. The author discusses the problems involved from the point of view of power economy. **The change-over in power generation from gas engines and Cornwall boilers to a back-pressure steam power plant** W. Rauschenfels (191–193) The layout of the old plant is compared with that of the new one and the economic advantages are outlined. **The advance from the gas engine via the (40-Atm) steam turbine to the gas turbine** A. Runkel (194–196) The advances made in power generation during the last three decades and its economic aspects are discussed on the example of the Hüttenwerk Rheinhausen, that changed its power plant in 1929 to steam turbines and is now installing gas turbines which will eventually replace all the steam turbines. **Generation of blast and power from blast-furnace gas and waste heat in steam power plants (87 Atm and 485°C) and in gas turbines** U. Jeltsch (197–199) The works at Dortmund of the Dortmund–Hörder Hüttenunion intend to install gas turbines for blast generation which will replace the existing gas engines. The power consumed will be generated in a steam turbine plant. **Trends in power and blast generation in integrated iron and steel plants** R. Simon (199–204) The present trend in power generation is towards large power units that not only supply the iron and steel industry but other industries too. The advantages of such large power units are outlined.—T. G.

On the nature of the isothermal processes in the blast furnace M. I. Kochnev (*Izvest. Akad. Nauk. Otdel. Tekhn.*, 1958, (11), 121–123) From practice and from the heat balance of blast-furnace smeltings it follows that the reduction processes develop to a considerable extent in the subsidiary zone of the blast-furnace and that intensification of heat exchange occurs, resulting in the appearance of isothermal processes. It follows also from the relations between the changes in the properties of the iron and its oxides due to temperature and the temperature disturbances in the blast furnace, that the appearance of the isothermal zone is due to the change in the composition, i.e. it depends on the principal reacting substances.

Automatic control of the composition and temperature of peripheral gas and control of the operations of the blast furnace Z. I. Nekrasov and Ya. M. Obodan (*Metallurg*, 1959, (2), 7–10) A device for continuous sampling and filtration of samples is described and also for automatic analysis and recording. The higher the CO_2 of peripheral gas and also of total gas the better the coke consumption is found to be. The CO_2 should not be less than 7–7·5%, unless a large amount of fines are used in the burden. Low CO_2 can be due to incorrect charge distribution at the top, to destruction of the lining or to blocking up of the centre zone. When composition is not uniform owing to unstable working it may help to change the charging temporarily to first adding coke and raising the level by $\frac{1}{4}$–$\frac{1}{2}$ m, to increase the ore charge in the case of long and hot working, to change blast conditions or slag basicity or to improve coke screening.—R. S.

Radiometric control of level of materials in blast furnaces I. G. Polovchenko, G. A. Vasil'ev, V. N. Afanas'ev, V. N. Uzlyuk, and A. L. Berin (*Stal'*, 1959, (3), 204–205) Replacement of mechanical by radiometric control is described, eliminating over-charging and giving smoother working.—R. S.

The design of large gas valves for blast-furnace gas A. J. R. Belford (*JISI*, 1959, **193,** Sept., 63–70) [This issue].

Distribution of gas streams in the blast furnace stack N. N. Babarykin (*Stal'*, 1959, (2), 101–105) As top gas pressure increases the cavities between the lumps of charge in the stack were reduced by 2·8–4·9%. The stream of gases in the upper part tended towards axial flow and the speeds of movement of charge and gas in the axial zone increased, whilst they diminished near the wall. The CO_2 at the periphery also decreased, mainly due to displacement of the basic mass of ore in the direction of the axis as the coke layer was less deformed by the ore. Static pressure of the gas at different points radially was practically the same whatever the top pressure.—R. S.

The gas turbine in Belgium steel industry J. G. Coutant (*Blast Furn. Steel Plant*, 1958, **46,** July, 718–721) A description of a gas turbine installed at the Soc. Mét. Hainaut–Sambre plant at Couillet in Belgium is given. The gas turbine provides air for a blast furnace and electric power. Operating results are very satisfactory and are discussed.—B. G. B.

Determination of gas transit time by radioactive tracer radon in a driving 1000-ton blast furnace M. Serizawa, Y. Kuzuhara, Y. Takahashi, K. Kanbara, and K. Miyakawa (*Tetsu to Hagane*, 1958, **44,** Nov., 1251–1259) Rn was introduced into a 1000-t blast furnace through a tuyere and gas samples were taken at frequent intervals at the top of the furnace. The samples were analysed in a pulsed ionization chamber. It was found that Rn introduced into the centre of the furnace reached the top more quickly than that injected near the lining. Gas flow is more regular in the centre than near the wall, and there is a definite relationship between the two showing whether a furnace is stable or not. The results are presented in tables with headings in English.

The smelting of conversion pig iron with the complete exclusion of manganese ore from the burden N. E. Dunaev, E. G. Ostrovskii, and N. N. Popov (*Metallurg*, 1958, (8), 8–10) In Southern Russia the S content of the coke is high and coke consumption is high, so that even where the consumption of Mn ore in the burden was restricted to 0·026 t/t cast iron, it proved impossible to reduce the Mn content of the cast iron below 0·52% (at 0·077 t the Mn content was 1·06%), although productivity rose by 6% and coke consumption fell by 6%. Experience with the complete exclusion of Mn ore from the burden shows that: (1) the burden should contain about 60% aluminous ores; (2) the basicity ($CaO : SiO_2$) of the slag should be raised to 1·28–1·30; (3) the alumina content of the slag should not fall below 7–10%, and the MgO content should be increased to 3–4% by the introduction of 20–25% dolomite to the burden; (4) the hearth temperature should be somewhat increased (Si content in the cast iron should be 0·7–0·9% and its temperature 1470–1500°C); (5) blast temperature should be raised to 750–800°C. The S content of the cast iron also fell appreciably. The editor adds a note that at another works in S. Russia a satisfactory slag has been obtained with 5·0–5·5% alumina but 5·5–6·0% MgO so that $CaO : SiO_2 = 1{\cdot}28$–$1{\cdot}30$ and $(CaO + MgO + MnO) : SiO_2 = 1{\cdot}45$–$1{\cdot}46$.—M. T.

Behaviour of fluorine in blast furnace smelting II. Smelting of Pao-Tau iron ore in an experimental blast-furnace Chow Jen, Chou Yuan-Hsi, Sun Tsung-Li, Hsu Yuan-Sun, Chow Sheng-Hsiang, Wang Wei-Yuan, Mow Pei-ken, Peng Hsui-wu, and Tsung Chia-Ting (*Acta Met. Sin.*, 1958, **3,** (3), 181–196) A furnace with effective volume $\sim 1 m_3$ was built and fluorite – containing ore smelted without sintering. Campaigns of 22 and 36 days were carried through and balances are given. Nearly all the F passes into slag and the content of the gas was very low.

Concerning the quality of blast-furnace pig irons L. I. Gol'denberg (*Lit. Proizv*, 1958, (9), 7–8) A review of the production conditions in the USSR and some suggestions for reducing the number of different types and standardization of the chemical compositions.

Research into the factors causing fluctuations in the silicon content of basic Bessemer pig iron J. Lemfeld (*Hutn. Listy*, 1958, **13,** (8), 675–679) High Si-contents reduce basic Bessemer output and an increase from 0·5–0·9% Si, for instance, increases the blowing time in the converter by 30–40%. The principles of Si reduction in blast furnaces are discussed, and varying conditions of blast furnace operation caused by changes in ore qualities, and the affect on the iron produced. Czech ores with relatively high Si contents are more readily fusible and facilitate the formation of a more viscous slag at lower furnace temps., whereas the lower Si content Russian ore used produces more refractory compounds which are not readily reducible. It is concluded that the composition of the burden and changes in the general operation of blast furnaces are the prime causes of variations in the Si content of basic Bessemer pig iron.—M. T.

The effect of CaF_2 on the distribution of phosphorus between liquid iron and ferro-calcareous slags I. Y. Kozhevnikov, O. V. Travin, and E. N. Yarkho (*Doklady A.N.*, 1958, **122,** (4), 635–638) The experiments were carried out under the conditions of successive saturation of iron by radioactive ^{32}P introduced into the slag, which allowed isothermal conditions for the metal-slag system and also determination of the temperature relations of the index of distribution of phosphorus, The introduction of CaF_2 into the slag leads to the

formation of stable ionic groupings in composition similar to fluorapatite. This suggests that the study of slags must be based on the concept of certain stable ionic groupings and the reactions must be interpreted in terms of 'molecular formulae'.—S. I. T.

Exploitation of hot metal transfer ladles in the blast furnace plant at Magnitogorsk G. I. Gerasimov, F. A. Korablin, V. M. Nemkin, and V. A. Lednov (*Stal'*, 1959, (2), 110–111) Flat-bottomed ladles were found more convenient and economical than spherical bottomed ladles. Diagrams are given of the Bamag-type ladles used at Magnitogorsk and of the Kling type, and of the Urals Machinery Plant design.—R. S.

Operation of the gas cleaning equipment with high top pressure operation M. N. Antsupov (*Metallurg*, 1958, (12), 11–13) Measures to be taken are described including increase of water pressure, cutting off the by-pass of scrubber valves and sealing the water valves of the scrubber.—R. S.

Lowering the sulphur content of pig iron during the blast furnace process I. I. Korobov (*Metallurg*, 1959, (1), 7–9) Ukrainian plants work with acid slag or Krivoi Rog ores, sinter and fluxes which have been relatively poorly crushed and screened. Blast temperatures have been low at 800°C and tuyere operation has been irregular. The measures now taken are, careful crushing to maximum sinter and ore size of 40 mm and flux size 50 mm, fines up to 2 mm are extracted, raising of blast temperature to 1100°, (when the stoves have been modified to 1300°C), and mixing the fluxes with the ore and dolomite limestone so as to produce not less than 5·5% MgO in the slag.

Desulphurizing potential [capacity] of blast furnace slag T. Negrescu (*Studii si Cercetari de Metalurgie*, 1956, (1), 49–64 [In Rumanian] 10 g specimens of the SiO_2-Al_2O_3-CaO system were heated in an electric furnace with 24 g synthetic Mn-free cast iron but containing 0·8% S in cylindrical graphite tubes 18 mm in diameter at 1460 and 1550°C in order to determine the maximum quantity of S which can be absorbed by the slag under conditions of equilibrium at each temperature. The relation involved is $100\ S = K_c\ (c \cdot q_s S)$ where S, c and s are percentages of S, CaO and SiO_2 contained in the various slags and K_c is a coefficient designated by the author as temperature coefficient. The values of the latter were found to be 1460°C, 4·084; 1500°C, 4·764; 1550°C, 5·718.

Wall erosion in the blast furnace K. Kodama, K. Miyatake, N. Nakamura, and M. Kase (*Tetsu to Hagane*, 1958, **44,** Oct., 1159–1164) Higashida No. 5 blast furnace of the Yawata Steelworks was dismantled after seven years' operation owing to expansion of the lining, which had lifted the charging assembly about 1 m. Investigation of the lining showed the mechanism of brick disintegration by alkalies, CO, Zn, Pb, etc. From the findings it is recommended that bricks of pore-free structure should be used, a shell-type design with as many cooling plates as possible, and a burden from which excess alkali, Zn, Pb, etc. has been removed.—T. G.

The use of water from slag granulation for cooling the blast furnace T. T. Nesterenko (*Metallurg*, 1959, (1), 9–10) The water used to feed the recirculation cooling was hard (10–20°) but that from slag granulation was soft (2–4°). Use of the latter for cooling avoids acid cleaning of the coolers, increases temperature drop and halves water consumption. Tuyeres and slag notches lasted longer and burning was almost excluded.—R. S.

Preliminary treatment of pig iron in ladles with a steam-oxygen mixture Ya. A. Shneerov, A. G. made between (1) treatment with this mixture Derfel', A. G. Kotin, M. T. Bul'skii, and A. G. Alimov (*Metallurg*, 1958, (8), 11–14) Experiments were carried out under semi-production conditions on the treatment of pig iron prior to melting in OH furnaces, thereby increasing their output by up to 15%. Preliminary treatment reduces the Si content of the iron from 0·7 to 0·3–0·4%, so that where pig iron constitutes 75% of the charge it is possible to run a phosphate slag with a high P_2O_5 content when refining phosphorus cast iron. Equipment for treating iron in the ladle is described. Pure O_2 was first of all used, but later a mixture with steam (H_2O 20–40% by weight), which prevented the liberation of brown vapour. In the experiments comparison was made between (1) treatment with this mixture alone, (2) treatment in the ladle with additions of 1·5–3% limestone, 2·5–5% ore or 1·5–2·5% ore + limestone, and (3) treatment with steam-oxygen mixture + 1·5%, limestone, ore or limestone + ore. As a result of (1) increased reduction of the Si content was not achieved, but Mn and C were both reduced by about 2% of the initial content and S by about 25% of the initial content; (2) for ore alone (5%) the figures were Si 60% less, Mn 58% less, but C increased; and (3) the reduction of Si was about 50–100% greater than as a result of (1). Other data are given concerning O_2 consumption, changes in temperature of the molten iron, metal losses and H_2 content.

Processes for the production of iron other than in the blast furnace J. Willems (*Stahl Eisen*, 1959, **79,** Jan. 22, 74–80) A description, review and appraisal of the various direct iron smelting processes.—T. G.

Two local methods of producing pig iron in the province of Shansi Kun Lin Tan (*Gantie*, 1957, (5), 85–89; from *Ref. Zhur. Met.*, 1959, (1), 298) Iron ore, anthracite or coke and flux were used in small blast furnaces with a stack diameter of 1 m and a height of 6·1 m and also in an open-hearth furnace of diameter 670 mm and a height of 2m. The cost of the iron is two to three times that of iron produced in normal blast furnaces and fuel consumption is somewhat higher but it is difficult to replace all local ironmaking with modern methods requiring high capital investment.—R. S.

Heat economy of the low-shaft furnace in the present state of development of the process in Eastern Germany G. Jacob (*Neue Hütte*, 1959, **4,** Feb., 75–84) Investigations on Nos. 4 and 7 furnaces at the Eisenwerke West, Calbe, Saale, are described and discussed. Lean Harz ores are smelted with crude limestone and coke consumption is high. CO_2 and water contents are high, and indirect reduction; taking into account decomposition of these substances, is 20%. Heat consumption is $5887 \times 10_3$ k.cal/t of pig iron, and thermal losses are high at 16%. It is expected that the use of burnt lime and calcined ore, (using flue gas as fuel) or a self-fluxing sinter will improve heat economy and production: (23 refs).

The low-shaft furnace at Lüttich L. Halbrecq and A. Decker (*Berg-Hütten. Monatsh.*, 1958, **103,** Oct., 189–200) An account is given of the series of trials carried out at Ougrée with the international low-shaft furnace; the design and operation of the furnace, layout of the plant, and the results of the trials are described and discussed.

The Krupp-Renn process in Germany D. Fastje (*Iron Coal Trades Rev.*, 1958, **177,** Nov. 21, 1223–1225; from *Tech. Mitt. Krupp*, 1958, **16,** (2), 34–38).

The Hoganas process: The use of sponge iron for steelmaking in Brazil A. C. Lopes (*Bol. ABM*, 1958, **14,** Oct., 573–614) Features of the industry in Brazil, abundance of ore with large amounts of fines, lack of coking coals and shortage of scrap, which favour the introduction of the direct reduction process are noted. The composition of sponge is given as prepared at Hogenas, in Brazil still less of the trace element would be included. These and other factors are discussed in detail and OH and electric furnace conditions are tabulated. Plant is outlined and costs estimated, and specifications for a plant in Brazil are set out.

A description of the technological process for producing pig iron from ferriferous sand by sintering with soda Koriuti (*Tokusuko*, 1957, **6,** (7), 62–65, 72; from *Ref. Zhur. Met.*, 1959, (1), 295) On sintering mixtures of sand and soda, viscous compounds of the oxides of Na, Fe and Ti are formed. Soda and reducing materials is charged into a drum furnace fired with fuel oil at 1300°C which transfers TiO_2 to the slag. Cast iron melts at 1400° and contains 3·82%C, 0·02%Si, 0·03%Mn, 0·151%P, 0·042%S, traces of Cu, 0·05%Ti, 0·01%Cr and 0·03%V. The low-grade coke used gave the high S and P.—R. S.

PROPERTIES, TREATMENT AND USE OF SLAGS

Microscopical investigation of the crystallization of blast furnace slag L. Pardov (**Svazek*, 1958, (2), 176–181) Work at the Brno Research Institute is described. Slag samples were allowed to cool naturally, this being so rapid as to leave some vitreous phase on the surface with a nucleated region inside and a crystalline core. Photomicrographs of these zones are given, illustrating the process of crystallization. Ordinary and polarised light examination was used. The final stage is melilitic.

Calculation of the active concentration of slag components from a consideration of the existence of ions and non-dissociated compounds N. M. Chuiko (*Izvest. Akad. Nauk Otdel Tekhn.*, 1958, (11), 7–14) The active concentration of the slag components are determined from the dissociation constants of the chemical compounds on the assumption that the slags consist of simple ions Me^{2+}(Ca^{++},Mg^{++},Mn^{++}, Fe^{++}) and O^{--} and non-dissociated compounds (silicates, phosphates, etc.). By measuring the thermodynamic reaction potentials, the dissociation constants of calcium silicate are obtained. The determination of the active concentration of the compounds in the CaO–SiO_2 system has shown that the active concentration of Si has an appreciable effect at low basicity (B-1) and decreases with increasing SiO_2 concentration, falling to a very low value when a basicity coefficient of 2 is attained. The active concentration of CaO increases rapidly with an increase in basicity of the slag (from 1 to 4) and hardly changes thereafter. The free and combined oxides of calcium in silicates have also been determined.

The activity coefficients of MnO and FeO in open-hearth slags H. L. Bishop jun., N. J. Grant, and J. Chipman (*Trans. Met. Soc., AIME*, 1958, **212,** Dec., 890–892) The activity coefficients of MnO in OH slags were determined and are presented as a function of slag composition. MnO is a more basic constituent than FeO as generally accepted.—T. G.

The activity of ferrous oxide in silicate melts C. Bodsworth (*JISI*, 1959, **193,** Sept., 13–24) [This issue].

Extracting sulphide inclusions from molten slags by means of the electric field V. V. Khlynov and O. A. Esin (*Doklady AN*, 1958, vol.123, (2), 326–323) The tests for the extraction of sulphide inclusions from liquid slag at approximately 1400° were based on the electro-capillary motion of the liquid metallic droplets. Slag composition in % CaO 15; Al_2O_3 10; SiO_2 43; Fe_{total} 20; MgO 10; Ni 0·1–0·2; Co 0·02 and Si 0·15–0·2, with carborundum conductors. Current strength 0·05–0·1 with a gradient of 7–15 v/cm. Results have shown the possibility of extracting completely the sulphide inclusions by making use of the electro-capillary motion.

The production of open-hearth furnace phosphate slags at the Azovstal' works F. F. Sviridenko and A. N. Popova (*Metallurg*, 1958, (8), 20–22) Since 1955 at this works OH phosphate slag has been milled and 340,000 t ground phosphate is produced per annum. The flowsheet is given of the treatment of the slags and their enrichment with P_2O_5. Factors governing the solubility of P_2O_5 are outlined, e.g. the contents of SiO_2, Al_2O_3 and Fe_2O_3, CaO, MgO and MnO, and the effects of varied operation of the furnaces are indicated.—M. T.

On the electrical conductivity of ferro-manganese slags I. Tanabe, K. Oku, H. Watanabe, and T. Toyota (*Nippon Kinzoku*, 1958, **22,** Mar., 114–117) The electrical conductivity of the MnO–CaO–SiO_2–Al_2O_3 system in the ranges 5–25% MnO and 0·78–1·43 CaO/SiO_2 was measured. The conductivity of 6% Al_2O_3 samples was measured at various temperatures and with different amounts of the other constituents, and hence iso-conductivity lines were plotted on the CaO–MnO–SiO_2 diagram. The conduction is shown to be ionic.—K. E. J.

The study of slags at high temperatures N. A. Molloy (*BHP Techn. Bull.*, 1958, **2,** Sept., 3–6) The shortcomings of the Ordway weldometer technique when applied to the measurement of the liquidus temperatures of Australian blast furnace slags are discussed, and the construction and operation of modified equipment are described.

The foaming of molten silicates C. F. Cooper and J. A. Kitchener (*JISI*, 1959, **193,** Sept., 48–55) [This issue].

WROUGHT IRON

Wrought iron learns new tricks R. B. Norden (*Chem. Eng.*, 1959, **66,** Mar. 8, 172, 174, 176) The corrosion resistance of wrought iron and its suitability for use in heat exchangers, in the Solvay soda process and with salt brines, are discussed. Its physical properties are tabulated.

Modified wrought iron has greatly improved corrosion resistance (*Ind. Heat.*, 1958, **25,** Sept., 1788–1792, 1784) After normal Bessemer conversion a reducing agent is added and the reduced iron is poured into an iron silicate slag. Excess slag is poured off and the sponge iron is squeezed into a bloom. Corrosion properties of this material are described together with its fields of application.—A. G.

New wrought iron has better corrosion resistance E. R. Best (*Mat. Design Eng.*, 1959, **49,** Feb., 100–102) Composition, mechanical properties and the corrosion resistance under various service conditions of 4–D wrought iron are given.

PRODUCTION OF STEEL

Irlam steelworks (*Brit. Steel.*, 1958, **24,** Nov., 368–370, 372) A general description following a visit of the ISI Engineers' Group.

The new Oxelösund iron and steelworks C. Sebardt (*Värm. Bergsmann. Ann.*, 1958, 18–28) A account is given of the post-war development of the Oxelösund iron and steelworks, present, and projected production being analysed.

Lenin iron and steelworks of yesterday, today and tomorrow L. Kistelski (*Prz. Techn.*, 1958, **79,** Feb., 81–83) The plant was designed to fill up the gap of 1·5 mil t/year in the national demand of 5 mil t of steel in 1957–1958. All the statistics concerning the size, materials, production, and future development are given.

Past, present and future of Lenin iron and steelworks L. Kistelski (*Prz. Techn.*, 1958, **79,** Feb., 123–126) The help of the USSR in the design of the works, financing of the construction, supplying of machinery and raw materials, and training of the staff is acknowledged. The present low productivity per man (half that in the USSR and one-third that in the USA) is due to the acute lack of qualified and experienced personnel. It is expected that when fully developed the works will produce 3½ mil t of steel per year.

British Oxygen's tonnage plant at Scunthorpe (*Brit. Steel.*, 1958, **24,** Nov., 356–357, 359)

New tonnage oxygen plant (*Iron Steel*, 1958, **31,** Nov., 539–542) The characteristics of the new 200 t/day plant at Scunthorpe are described, with an outline of the process illustrated by a flow diagram. Some examples of the use of the oxygen in steelmaking are given.

Discussion on the paper: Comparison of the economics of different types of steelmaking processes, with reference to the development of ferrous metallurgy in Eastern Germany K.-F. Ludemann (*Neue Hütte*, 1959, **4,** Feb., 73–74); *see* 1958, **3,** Aug., 462–474). In comparing yields from various converter processes, these must be referred to a comparable final phosphorus content, when considering the iron losses due to slag iron content. Emphasis is laid on the advantages of the oxygen-steam process.

Operational experience with oxygen equipment at Azovstal' A. I. Stolyarov (*Kislorod*, 1958, (5), 39–47) The oxygen plant at Azovstal' went into operation in 1951 to supply oxygen for OH steelmaking, for welding and cutting and to supply Kr concentrate for the production of 90% pure Kr. Some measures taken to overcome certain difficulties associated with the supply and demand of oxygen as described. Oil distribution for the compressors had to be centralized and a new system of emulsion lubrication was devised. Operation of the oxygen compressors was improved.—R.S.

New trends in steel production J. Bečvář (*Hutnik*, 1958, **8,** (9), 290–292) [In Czech] Various recent suggestions for new types of steelmaking processes and furnaces, e.g. the direct reduction of ore, and the increasing importance of oxygen in converter and other methods are reviewed.—P. F.

The dynamics of the steelmaking processes W. Heischkeil and T. Kootz (*Stahl Eisen*, 1959, **79,** Feb. 19, 205–210) The authors compare the dynamics and metallurgical processes of the two classical steel refining methods with the new processes introduced during the last few years in order to arrive at an appraisal of the new steelmaking processes.—T. G.

On the vaporization processes in the metallurgy of steel V. M. Zamoruev (*Stal'*, 1958, *Steel melting processes supplement*, 127–150) The losses by vaporization can occur (*a*) by the vaporization of the metal and subsequent oxidation of the vapours (Fe, Mn, Al) or (*b*) oxidation of the metal with subsequent sublimation or vaporization of the metal oxides (W, Mo, Ti, P, Fe). During the melting of the charge both in the OH and in the electric arc furnace, iron losses due to sublimation and vaporization amount to no less than 0·4%. Melting the steel charge in the arc furnace and in an oxidizing atmosphere sharply reduces the iron losses due to vaporization and when melting iron in a crucible induction furnace the losses due to vaporization become negligible.

Quality control in specialty steel production J. S. Pendleton jun. and H. O. Beaver jun. (*Met. Prog.*, 1958, **74,** Nov., 100–103) Steps which have improved the consistency of quality of speciality steel bars and billets are described. They involve attention to control of scrap, metal composition and temperature and freezing in the ingot mould.—D. L. C. P.

Critical review of mechanization and automation in iron and steelworks. K. H. Hüser (*Stahl Eisen*, 1959, **79,** Jan. 22, 65–73) A lecture. The author discusses the technical and economical basis for a successful mechanization and automation of the iron and steel industry.—T. G.

Automatic control of scale cars M. B. Kutner and D. I. Pruzhanskii (*Stal'*, 1959, (1), 5–9) A number of Russian designs are shown and discussed. The programming of the apparatus, the ordering and fixing of the weight of the materials are described. Tabulated details are given for the six main schemes.—R. S.

Russian continuous converter R. Sewell (*Iron Steel*, 1958, **31,** Nov., 523–524) The converter is a long tapping spout, along which molten pig iron travels and is refined by top blowing with oxygen through a series of nozzles. The process has been found useful for recovering V from high-P, V-bearing irons.

Production of molten steel in a side-blown converter (*Met. Constr. Masini*, 1958, (10), 856–860) [In Rumanian] Converters used are of Robert or Tropenas type. A full description of the process is given. A typical result is the following: Pig iron 2·8%C; 0·5%Si; 0·44% Mn; 0·34%S; 0·050%P. The resulting steel gave the analysis: 0·04%C; 0·06%Si; 0·04%Mn; 0·020%S; 0·057%P. Time of blow, 8 min. Consumption of reducing agents: in percentages FeSi 0·8; FeMn 1·1; Al 0·15. The steel obtained can be utilized in the production of agricultural machinery, heavy machines; trolleys for cranes, presses, etc., machines for the petroleum industry and for coal mining and shipbuilding. The steel is 12% cheaper than OH steel.—L. B.

Prevention of brown ferric oxide fumes by steam blowing H. Kosmider, H. Neuhaus, and P. E. Hardt (*JISI*, 1959, **193,** Sept., 6–11) [This issue].

A study on the dephosphorization equilibrium in the LD converter. The application of Chipman's equilibrium formula M. Maeda, K. Tajina, and E. Homma (*Tetsu to Hagane*, 1958, **44,** July, 733–739) Readings were taken from slag and metal samples from a 3-t experimental converter. Values of the dephosphorization constant calculated from O_2 in metal agreed with Chipman's values; those from (FeO) in slag showed a discrepancy. The effect of 'after-blow' or dephosphorization is less than in a bottom-blown converter. Relationships are shown between N_{CaO} and N_{FeO}, and between phosphorus distribution ratio and N_{FeO}.—K. E. J.

The third session of the Steel Production Section of the Permanent Ferrous Metallurgy Commission of the Economic Mutual Help Soviet M. A. Pertsev and D. A. Smolyarenko (*Metallurg*, 1958, (8), 22–24) Meeting at Dnepropetrovsk in April 1958, representatives of the Communist bloc countries considered *inter alia* that: (1) The basic method of steelmaking in their countries is still the use of OH furnaces, but since steel obtained by oxygen injection of blast furnace conversion pig iron should be close in quality to that of OH steel (especially low-alloy steel), steel production in converters with the use of oxygen should be developed. (2) New types of high-quality refractories should be used to prolong the life of steelmaking furnaces and the following standards set for refractories. Chrome-magnesite, start of deformation under a load of 2 kg/cm², 1550°C, apparent porosity < 17%, refractoriness (heated to 850°) > 100 changes in temperature and correspondingly for spinellides for repair work 1600°; < 14% and > 100 changes. For checkerwork in regenerators it is recommended that brick should contain > 42% Al_2O_3 and have a maximum porosity of 18%. (3) Standards for steel for ball and roller bearings. The chemical composition of two types was agreed on: No. 1. 0·95–1·10% C, 1·30–1·65% Cr, 0·027% P, < 0·020% S, < 0·30% Ni < 0·30% Cu < 0·50% Cu + Ni and 0·30–0·50% Mn and 0·15–0·35% Si; No. 2. As for No. 1 except 0·90–1·20% Mn and 0·40–0·65% Si. It is intended to further improve the quality of these steels.—M. T.

Open-hearth shops of the U88R K. C. McCutcheon (*J. Met.*, 1958, **10,** Nov., 724–726) An account is given of Soviet OH practice. The high outputs achieved are attributed particularly to the use of water-cooled hot metal spouts and suspended basic furnace roofs.

Converting a 400-ton open hearth furnace to sulphurous fuel oil firing F. D. Voronov, E. I. Dikshtein, K. A. Zuts, and A. G. Trifonov (*Stal'*, 1959, (2), 112–116) With the new system for the first 274 casts, fuel consumption was 105 kg/t steel, tap-to-tap time was ~12·25 h, checker life after the first hot repair was 274 casts instead of 170 and the volume of replaced lining during minor cold repairs was 260 m³ instead of the usual 350 m³. S content increased with 2% S in the oil, thus reducing the number of types of steel that could be produced. Fan and nozzle arrangement is described and graphical data is presented.

Modernization of open hearth furnaces I. M. Koburneev and V. P. Pogorelyi (*Stal'*, 1959, (3), 224–226) The rebuilding of the furnaces in No. 2 shop at Dzershinak is described. Output per furnace since 1956 and fuel consumptions are shown, including the period of changeover to chrome-magnesite roofs, and also variation of heat input during the various periods of a heat in the modernized furnaces, with diagrams of the air uptakes showing flue valve arrangements. Water sealed valves, separate feeds to them for coke-oven and blast furnace gases, deepened checkers, increasing their volume from 3·96 to 4·35 m³/m² of hearth area and a bottom reinforcement to preserve the shape and to reduce air leakage. Roofs of slag pockets are lowered and the distance from the buck stays increased.—R. S.

Investigation of schedules for reversing open hearth furnace valves A. I. Chernogolov, Yu. A. Voinov, and E. A. Ploshchenko (*Stal'*, 1959, (1), 31–42) Reversal schedules according to the counter-gas system of Giprostal and Stalproekt are described. Where blast furnace gas distribution is controlled on both sides of the furnace the Giprostal schedule is used and in all other cases the Stalproekt schedule is recommended.—R. S.

The service of high alumina bricks in the regenerator checkers of open-hearth furnaces V. A. Rybnikov, E. A. Volynskii, and G. V. Vodop'yanov (*Refract. J.*, 1958, **34,** Dec., 552–554; from *Ogneupory*, 1958, (3), 109–111) High-alumina sillimanite bricks have been tested in the air checkers of an 80-t furnace at the Izhorskii plant. The bricks are said to be superior to forsterite, chrome-dinas and fireclay bricks. Wear occurred through the destruction of the mullite phase by fluxing dusts and better results might be expected from refractories of lower silica content.—A. G.

'Compacted' monolithic linings and their applications to steelmaking furnaces R. Blondel (*Centre Doc. Sidér. Circ.*, 1959, (1), 177–200) The advantages and disadvantages of basic (dolomite or magnesia) monolithic linings

compared with brick linings are enumerated, and the importance of grain size is shown. Experiments and works trials using dolomite with a maximum grain size of 12 mm have given very satisfactory results, and techniques for ramming tar-dolomite mixtures or vibrating dry dolomite are described. It has been found possible to reduce the tar admixture for ramming to 6–7%, which has given improved properties.

Improving the construction of bridge walls in slag pockets M. A. Kovshar' (*Stal'*, 1959, (2), 128–129) OH furnaces of 90-t and 185-t capacity operating on blast-furnace and coke-oven gases suffered many stoppages due to the short life of the bridge walls of the slag pockets. Thickening from 1115 to 1345 mm and replacing the chrome-magnesite brick layer 195 mm thick by chrome ramming mass 115 mm thick did not improve the position. In 1952 one of the furnaces was fitted with a Dinas bridge wall 1575 mm thick without intermediate layer and protective walls of chrome-magnesite bricks 345 mm thick. Even this did not give the desired result. When the 185-t furnaces were commissioned it was found that their 1280 mm bridge walls did not burn through as rapidly and usually lasted two campaigns per roof; also there was considerable roof deformation in the slag pocket and the life of the gas uptake linings was very poor. At the beginning of 1957 one 185-t furnace was shut down for >4 days from these causes. Alterations reducing the load on the roof and transferring it to the bridge wall eliminated the trouble.—R. S.

Preliminary deoxidation and the hydrogen content of steel M. A. Druyan and V. M. Soifer (*Stal'*, 1959, (3), 221–224) The increase in H_2 after addition of blast-furnace Fe–Si is due to fixation in the Si-killed metal. Tapping from the furnace in the rimming state promotes efficient degassing and considerable decrease of H_2. Elimination of embrittlement and production of sound metal results with only small additions of Al.—R. S.

Construction tool slashes furnace maintenance costs (*Steel*, 1958, **143,** Dec. 8, 116–122) Steelworks uses of the 'Gradall' earthmoving and construction machine are described. They include: stripping furnace linings, cleaning out slag-pits, handling wire coils. The machine has a triangular telescoping boom which carries the working attachments and which can be swung in a complete circle, raised, lowered and tilted.—D. L. C. P.

Scraper apparatus for removing slag from steelmaking furnaces (*Stal'*, 1959, (1), 43–44) Two types of machine are illustrated, one fixed to the peel of the charging machine and operated by the charging machine driver, and the other fixed on its own carriage. The machine is completely mechanized and the scraper has a reciprocating movement.—R. S.

Effect of checker-work design and operation on preheating of air and gas in three gas-fired open-hearth tilting furnaces H. Voigt and G. Schmalhaus (*Stahl Eisen*, 1959, **79,** Jan. 22, 80–88) The results of studies on three, 150-t capacity, tilting OH furnaces during whole campaigns showed that the manner in which the waste gases impinge on the checker work is the decisive criterion for high heat-transfer, and not brick thickness, weight of the checkers or type of brick. High resistance to air and gas flow promotes impingement and so checker-work with a high flow-resistance is to be preferred.—T. G.

Slide rule for calculating the open-hearth burden I. Ya. Kuz'michev (*Stal'*, 1958, *Steel melting processes supplement*, 272–285). A 10 cm slide rule is described the use of which increases the accuracy of the calculations. So, for example, at the Kuznetsk Metallurgical Combine in 1953, 2% of the burdens had to be recalculated, whilst since 1956, when this slide rule was introduced, only 1·34% were subject to corrections or adjustments.—L. H.

Automatic control of open-hearth furnaces in the USSR V. Yu. Kaganov (*Stal'*, 1959, (1), 16–24) Rapid-acting contactless electro-hydraulic and electrical instruments are described used for combustion and flame reversal control. Continuous temperature measurement of both metal and combustion products is discussed. Control programmes are given in relation to heat input and according to roof parameters. Pressure control in the furnace chamber is also reviewed.—R. S.

Rational feed of compressed air in the open-hearth I. M. Koburneev, S. A. Petrov, A. A. Sorokin, and I. S. Timoshpol'skii (*Stal'*, 1959, (3), 212–214) Compressed air is fed in subdivided streams through small pipes laid inside the doghouse. Substantial increase of roof life was achieved with increased productivity and decreased fuel consumption. A diagram is shown and details of heats with and without compressed air are given.—R. S.

The use of non-sintered magnesite-chromite refractories in the vaults of open-hearth furnaces G. G. Aristov and K. K. Strelov (*Stal'*, 1958, *Steel melting processes supplement*, 241–252) The use of these bricks has made it possible to feed an increased supply of fuel and intensify the process. The roofs, however, which have been calculated for furnaces with dinas vaults, would not, in many cases, withstand the intensification of the melt. By using non-roasted magnesite-chromite refractories for OH roofs the productivity of the furnaces was increased by 4–8%.—L. H.

Major repairs of a 260-ton open-hearth furnace in 140 hours V. E. Pis'mennikov (*Metallurg*, 1958, (11), 26–27) In April 1958, a 260-t furnace was given major repairs in the record time of 140 h. About 1300 t of metal structure was dismantled and a new lining, weighing over 3000 t was put in. A description of some of the equipment used for mechanical handling and for heating up is given.—R. S.

Experiences of the Kazakhstan metallurgists N. Ishmukhamedov (*Metallurg*, 1959, (2), 19–20) Two methods of burning in the bottoms of OH furnaces are described. One uses magnesite layers (70–75% MgO) each 20–25 mm thick and burning-in is prolonged to achieve regeneration of periclase grains, the other uses layers containing fluxes (slag or millscale). Further details of experience in burning-in are given and how these methods have reduced repair times.—R. S.

Open-hearth fuel atomization with a reaction-type jet burner A. L. Hodge and G. W. Hinds (*Iron Steel Eng.*, 1958, **35,** Dec., 88–86) It is shown that the use of the jet reaction flame to atomize liquid OH fuels produces firing rate increases up to 30% and increases in production rate of 8–12%.

Inter-works school for open-hearth furnace bottom repairs G. E. Germaidze and V. G. Pushkov (*Metallurg*, 1959, (2), 13–16) The school was established in July 1958. Stoppage times for various works are given for 1957–1958 with best, worst and average figures and descriptions of repair methods at three large works are given. It was recommended that repairs should be scheduled on a weekly rather than a monthly basis, repair times should be adhered to as set out on the schedule. Compressed air at >5atm should be used to clear slag and metal and where possible, O_2 at 6–9 atm with the fuel off or reduced to a minimum. When used it is fed through three heat-resisting steel pipes simultaneously.—R. S.

The use of oxygen in the repair of [OH] bottoms and for increasing hearth life N. L. Lapin (*Metallurg*, 1959, (21), 16–18) The output from large basic furnaces at Nizhne Tagil was increased by cutting down repair times by using O_2. Slag and metal are blown off the hearth and the hollows filled with magnesite powder during fettling. A picture of the three tubes used is shown (*see* previous abstract). During blowing, roof temperature drops to 1300–1400°C; it takes 25–30 min against the 1½–2 h with compressed air.—R. S.

Aerodynamics of the gas flow in open-hearth furnaces V. Parma (*Sbornik. Ostrava*, 1958, **4,** (3), 253–267) [In Czech] The usefulness of scaled-down models of OH furnaces for studies of gas flow and combustion processes is considered, mainly by reference to published work. A model of a 200-t furnace is now being developed in the author's laboratories.—P. F.

Automatic control of thermal conditions in open-hearth furnaces N. S. Skorik (*Metallurg*, 1958, (11), 18–25) Large OH furnaces at Nizhne Tagil are fired with a mixture of coke-oven and blast-furnace gas and use oxygen for boosting the flame. Tar or anthracene oil is used as a carburetting agent. This article deals with control of thermal conditions, measurement of roof temperature, measurement of consumption of carburetting agent and of oxygen and discusses uniformity of heating of gas and air checkers and the automatic control of combustion. The system of automatic control embraces reversal, combustion with correction according to the analysis of the waste gases as regards oxygen, pressure control in the furnace chamber, control of the distribution of the products of combustion between gas and air checkers and automatic control of heat input.—R. S.

Automatic control of the thermal regime of open-hearth furnaces K. Řiha and O. Obdržalek (*Hutník*, 1958, **8,** (7), 218–221) [In Czech] Methods employed and results obtained in the automatic control of OH furnaces are evaluated, mainly on the basis of recent developments in the Soviet Union. Automatic control of the thermal regime should result in a saving of 8–15% on fuel, 5–10% on refractories, and in an increase in the yield per furnace by 7–12%.—P. F.

One fan serves steel plant furnace or waste heat boiler E. M. Ferris (*Ind. Heat.*, 1958, **25,** Sept., 1718–1724, 1873–1876) Steel furnace waste gas at 2000°F is often passed through a waste heat boiler. A single fan may be used for handling this gas or as an induced draught fan for the furnace and boiler operating together.

Improving traffic on the open-hearth stage A. I. Sharov (*Metallurg*, 1958, (12), 23–25) The greatest transport problems arise from the number of dead-end sidings in OH plants. Increased use of curved switch rails and of special points is suggested.—R. S.

Deoxidation and alloying of steel A. Děkanovsky (*Hutník*, 1958, **8,** (8), 263–269) [In Czech] The chemistry and physics of the various methods and stages of deoxidation of steels are discussed, and the effect of deoxidation technology on the structure of the steels is considered.—P. F.

Steel production process for section-shaped castings N. N. Dobrokhotov (*Lit. Proizv.*, 1958, (12), 8–9) An increase of relative elongation without at the same time reducing the strength properties of steel can be attained only by improving the method of production; for example, by a higher metal temperature before tapping and by the formation of a more basic slag. Ni increases the impact breaking strength. Additions of Al improve the casting properties of the steel. Ti and Al have great emissive power and hence steel containing increased quantities of these elements shows, when its temperature is read by the optical pyrometer, higher temperatures than are actually present.

Removal of slag from slag pockets N. I. Efanov (*Metallurg*, 1958, (11), 47) A competition was held in 1957 by the 'Scientific and Technical Association of Ferrous Metallurgy' for the development of methods to remove slag from OH slag pockets and also for cleaning checkers. Eighteen suggestions were made regarding slag removal and ten suggestions for cleaning checkers. Slag removal suggestions referred to the removal of solid slag by mechanical methods and to the removal of liquid slag. The best suggestion came from Nizhne Tagil for the removal of slag by using a tractor equipped with special hinged devices. This is not described in detail here. Suggestions for removing liquid slag provide for the use of special holes to tap the slag from the pockets. Before slag is tapped from the slag pockets in the liquid state, the temperature is brought up by means of special burners. A special mixture is periodically introduced into the slag pockets to keep the slag in the liquid state. As regards checker cleaning, one idea was to brick the checkers like a hot blast stove. The top 10 to 12 courses of the checkers are of the hot blast stove (Cowper) type and in forsterite. One inventor suggested coating the checker bricks with a special suspension of chrome magnesite powder. The checkers would be cleaned by a series of explosions set off in the vertical plane. Other methods were high-frequency vibrations on flexible tubes and blowing with compressed air and water. Vacuum pumps are also suggested for cleaning checkers. One suggestion which earned a prize of £500 was the use of a

vacuum conveyor for removing dust from beneath the checkers and from the flues of OH furnaces. No details are given.—R. S.

Chemical control of incomplete combustion and the coefficients of excess air in open-hearth furnaces S. G. Troib (*Stal'*, 1958, *Steel melting processes supplement*, 253–271) Interaction between the burden and gases causes great reciprocal variations of the various coefficients so that the lower the specific fuel consumption the further the numerical values of the various coefficients deviate from their initial value as adjusted to the fuel feed. A method is described for a continuous chemical control of these variations, and the method is equally applicable to cupolas.—L. H.

Automatic pressure control in open-hearth furnaces by the distributor side valve Yu. N. Tuluevskii (*Stal'*, 1958, *Steel melting processes supplement*, 236–240) A description is given of a vertical distributor and of a typical pressure diagram obtained under the vault by this type of regulator. After two years' experience, it is recommended for large furnaces.—L. H.

Regenerator efficiency J. Spal (*Engineering*, 1958, **186**, Dec. 26, 819–820) A letter. Difficulties in the measurement of gas and wall temperatures and the fact that surface and average temperatures of the packing are very different unless on so long a cycle as to be quite inefficient are pointed out.

Effect of manganese on the oxidizing properties of silicon in liquid iron Du Tin and A. M. Samarin (*Acta Met. Sinica*, 1958, (3), 210–226) This is a survey from the literature of the experimental methods for the determination of oxygen solubility in pure iron, and determines the influence of Mn on the oxidation of Si in various concentrations and at various temperatures. The nature, the form and the quantity of the oxidation products of Si and Mn are studied, also the equilibrium constant and the change in the free energy of oxidation of Si and Mn and the elasticity of the oxidation products.

Relation between hydrogen content in slag and metal during the melting of steel I. I. Begletsov (*Stal.*, 1958, *Steel melting processes supplement*, 285–313) Experiments have established that in basic furnaces at the end of the melting period, hydrogen content in the metal (all per 100 g of metal) is between 11–13 ml and in an acid furnace, between 9–10·5 ml. In the scrap process, in the basic furnace at the end of decarburization it is between 11 and 12·7 ml and in the slag between 17·6 and 22·7 ml. In melts with alumina-magnesia slags at the end of decarburization 8·5–10·5 ml and in melts in acid OH furnaces between 5·8 and 7·4 ml in the metal, and between 5·6–8·3 ml in the slag.

Concerning the uniform distribution in the slag of the small additions during the melting of steel in the 350-t furnaces A. I. Osipov, L. A. Shvartsman, E. V. Iudin, and M. L. Sazonov (*Stal'*, 1958, *Steel melting processes supplement*, 218–224) The investigation was undertaken to elucidate the fact that radioactive CaO, chief component of basic OH slag, does not pass into the metal but remains practically completely in the slag. In the slag itself distribution proceeds very slowly and takes approximately 30–35 min. It has also been shown that the aerodynamic pressure of the flame exerts a powerful influence on the distribution of the radioactive Ca.—L. H.

The use of manganese in various processes of open-hearth production N. S. Mikhailets, A. I. Borodulin, and L. S. Klimasenko (*Stal'*, 1958, *Steel melting processes supplement*, 44–62) Production of rimming and rail steels was investigated. The findings show that the metal assimilates only 6–12% of the Mn contained in the charge (i.e. in the molten iron and scrap). Hence an appreciable reduction in Mn content in the molten iron and scrap results only in a relatively small decrease in its content in the metal. Using low-Mn iron increases the consumption of Fe-Mn in the OH furnace by 0·8 kg/t for rimming steels and by 1·8 kg/t for rails. This increases the price of steel by 0·35–0·75% but at the same time the use of cheaper pig iron with less Fe-Mn reduces the price by 3·10–2·51% to which must also be added the advantage of less phosphorus content.—L. H.

Thermodynamics of the reaction of dephosphorization of liquid iron by four-component slags of open-hearth furnace type I. Yu. Kozhevnikov and L. A. Shvartsman (*Izvest. Akad. Nauk. Otdel. tekn.*, 1958, (10), 104–109) Thermodynamic conditions of the reaction of dephosphorization of iron by slags of the system $CaO–FeO–SiO_2–P_2O_5$ are important for the improvement of the smelting process. The object of this research was the determination of the influence of SiO_2 and P_2O_5 on the variation of thermodynamic functions of the phosphorus reaction; ^{32}P was used, and slags were prepared synthetically from chemically pure reagents. Radioactive P was introduced into slag as $CaO·P_2O_5$. Tests were carried out in an induction furnace in an atmosphere of N_2; temperatures were kept at 1580–1760°C, the heat ΔH of the transfer of P into the slag from the metal and the volume distribution L_p of P were determined. It was found that introduction of SiO_2 into the slag of the system $CaO–FeO–P_2O_5$ brings about a decrease in the heat of the dephosphorization from 92 kcal/g to 68 kcal/g. This value remains fairly constant and independent of the slag composition. The equilibrium of P distribution between iron and slag is determined by the change in the entropy of the P reaction, which depends on the slag composition. When temperatures of slag and iron differ, this difference determines the new distribution of P.—S. S.

Oxidation conditions relating to phosphorus during the melting period I. J. Koshevnikov (*Fiz. Khim. Osnovo Proiz. Stali*, 1957, 143–167) To produce primary slags high in P and to accelerate dephosphorization an oxidizing agent should be used in the charge. The best is scale or a briquette of scale and limestone, (briquettes yielding a slag of 20% CaO 80% FeO melt at 1230–1250°). The use of these instead of 70–80% iron ore and their distribution in the top layer of the non-metallic charge gives a slag with 12–18% P_2O_5 and the refining period is reduced by 1½ h. Tables of trial heats, slag compositions and basicity and method of slag removal are given.—R. S.

Rate of desulphurization of mild steel in the basic open-hearth process M. Takamuku, K. Okamoto, and T. Fujii (*Tetsu to Hagane*, 1958, **44**, Aug., 866–872) Results of test melts with extra-low-carbon rimmed steel show that as little lime must be used as possible in the refining period, the slag before melt-down must be used effectively for desulphurization, the basicity must be increased at the beginning of the refining period, and the C–O boil must be used effectively for desulphurization.—K. E. J.

Desulphurizing properties of ochre (2) G. Yamaguchi and A. Sekiguchi (*Tokyo Univ. Ann. Rep. Eng. Res. Inst.*, 1958, **17**, Sept., 49–50) Four samples were examined and desulphurizing power was related to solubility in HCl.

The behaviour of sulphur at the time of the addition of alloying elements and of the deoxidation of steel U. T. Lukashevich-Duvanova and V. I. Karsanova (*From '*The physico-chemical Principles of Steel Production*', pp. 590–601) [In French] Mn, Cr, Mo, V and Ti and the deoxidants Fe-Mn, Fe-Si, Si-Mn, Si-Mn-Ca and Si-Mn-Ca-Mg were examined and the inclusions produced were separated and identified. Ti and alloys containing Si and Mg were effective in rendering the S harmless.

The problem of improving the scrap-process for quality steels in basic open-hearth furnaces M. M. Churakov and A. E. Khlebnikov (*Stal'*, 1958, *Steel melting processes supplement*, 27–43) Investigations on an industrial scale of a new process of making Cr-Ni structural steel in basic 30-t OH furnaces burning fuel oil without oxygen are detailed. The main characteristic of the new process is the increased intensity of the boil in the bath, a low Mn content during boiling (no ferromanganese additions) and the use of Si-Mn for preliminary deoxidation. The method worked out for such a steel for rough casting has shown that the mechanical properties are increased and that the economic indices are improved because of a reduction in the duration of the melt and an economy in the cost of ferroalloys.—L. H.

Production of tubing steel by the scrap process with low-manganese iron A. G. Derfel' and P. A. Kravtsov (*Stal'*, 1958, *Steel melting processes supplement*, 19–26) Two series of investigations were carried out in the 185-t. fuel oil burning OH furnaces, with magnesite-chromite vaults, using low-Mn iron based on the usual technique in use at the K. Liebknecht works, one excluding only the addition of Mn during finishing and the other including the addition of ferromanganese. The findings show that the duration of the heat remained unchanged in both cases as did also the consumption of iron. The ferromanganese consumption in the deoxidation of melts compared with the usual pig iron increased from 4·2 kg to 5·7 kg/t and with melts without ferromanganese additions to 6·2 kg/t. Rejects, consumption coefficients, mechanical properties, macro and microstructures were the same as produced by the usual process. Thus low-Mn iron can be used for steelmaking by the scrap process.—L. H.

On the advantage of melting tubing metal without preliminary deoxidation K. K. Prokhorenko, G. S. Kopit, A. I. Urinson, and A. V. Lomakin (*Stal'*, 1958, *Steel melting processes supplement*, 11–18) At the end of the finishing period, when carbon content attains the percentage corresponding to the upper limit in the finished steel, ferromanganese was introduced into the bath. The findings of the investigation show that the H_2 content was thus reduced by 15–20%, the loss by combustion of Si and Mn during oxidation was similarly reduced and the time of the melt was shortened by 15 min. The quality of the ingots improved owing to the reduction in the quantity of internal and external flaws.—L. H.

Recirculatory recuperative steelmaking furnace M. A. Glinkov and G. I. Demin (*Stal'*, 1959, (1), 24–31) A description is given of a 10-t experimental furnace fired simultaneously from both ends. The quality of the steel obtained is not inferior to that from the basic OH furnace. The use of the Glinkov furnace is likely to be particularly effective for low-C steel. A case for building a 50-t or 100-t unit operating on fuel oil or high-calorific gas, either cold charged or based on hot metal, is made out.—R. S.

Production of high grade steel by duplexing with converter metal and electric steel V. Kyuncher and Yan Tung (*Stal'*, 1959, (3), 215–221) Production of high-grade steel is increased 140% and cost is reduced 18% by this method of working. Removal of S amounts to 48% or more. Maximum 0·06% S in the converter steel gives mixed steel with $<0·015\%$ S. Best results are obtained with a slag ratio of ~3·6 before mixing, the slag containing $<0·5\%$ FeO and the mixing rate being 80–140 kg/sec. Mixed steel has 0·002–0·005% less N than the electric steel. With a ratio of electric to converter steel of 1 : 1·45 which is the maximum, the cost was 18·27% below that of electric steel. Oval ladles must be used for mixing. On a large scale a bottom or top blown converter should be used, but for smaller amounts, side-blown basic converters should be used.—R. S.

Survey of perspectives of the electrochemical study of iron- and steel-making K. Sanbongi and M. Ohtani (*Tetsu to Hagane*, 1958, **44**, July, 779–794) A review, with forty references.

Process adds economy to electric furnace smelting (*Iron Age*, 1958, **182**, Oct. 9, 81–83) A description is given of the Strategic-Udy process for the direct reduction of iron ore. Preliminary reduction is effected in a kiln using coal and the hot ore is then charged direct to the smelting zone of an electric arc furnace. High iron recovery, control of carbon content and low capital cost are among the advantages claimed.

How to make more steel (*Met. Prog.*, 1958, **74**, Nov., 97–99) It is described how, at a plant of Republic Steel Corp., an increase in steelmaking capacity of 40% was effected without adding more melting units. Blast furnace capacity was increased from 1 300 to 2 000 t per day by installing a new blower, relining, and effecting other repairs. Electric furnaces were converted to top charging, and enlarged.

Improving utilization of transformer capacity of large electric furnaces S. A. Morgulev (*Stal'*, 1959, (1), 49–53) A considerable improvement

in performance was obtained without adversely affecting furnace lining. The question of stabilizing electrical conditions is discussed.

Exploitation of electric arc furnaces with high secondary voltage D. F. Gladkii, V. F. Ivan'ko, and V. V. Kurganov (*Stal'*, 1959, (1), 45–48) The use of high secondary voltage with coupled transformers during the melting period has shown it to be possible to reduce the time required for melting and to economize in electric power without fall in steel quality and without adverse effect on furnace lining.

Control gear as applied to electric furnaces (*Wild-Barfield J.*, 1958, **6,** Dec., 10–14) Problems involved in the control of electric furnaces, such as methods of temperature control, types of contact faces, and limitation of input voltage are considered.—A. G.

Lining of electric furnaces A. N. Glazov and V. I. Mesyats (*Metallurg*, 1959, (1), 14–19) Since 1953 large unfired chrome-magnesite wedge bricks in steel sheaths have been used for arc furnace walls, their strength is 420 kg/cm², porosity 12·5% and composition 68·3% MgO, 10·4% Cr_2O_3. The first two courses above the slag line are laid with bricks 430 mm long and the rest with 300 mm bricks. Tap hole design and fettling technique are discussed and tapping procedure is described.

Cast and rammed sections in arc-furnace roofs J. D. McCullough (*AIMME Elect. Steel Furn. Conf. Proc.*, 1957, 45–59); *Ind. Heat.*, 1958, **25,** Sept. 1825–1845; Nov., 2325–2328) Roof construction at four plants is described and illustrated. Monolithic refractory constructions reduced roof costs by up to 30%. Materials suitable for the purpose and precautions in construction are noted. **Canadian basic refractory practice in electric furnaces** A. H. Thomson (60–64) Materials and locations for their use are surveyed. **Tar-bonded basic refractories** J. P. Holt (65–72) Compositions for use in oxygen steelmaking vessels are described. **Self-baking refractory mix** L. A. Stoyell and T. R. Culbert (85–91) Water-glass bound mixes of magnesite, silica or zircon sands and silicon carbide were used in various locations and tested by a compression method. Uses are briefly indicated. Particle size is important and Si metal powder is added to give a sufficiently strong product.

Power utilization and control in the electric furnace steel plant F. W. Foster (*AIMME Elect. Furn. Steel Proc.*, 1957, 191–201) In discussion, experience at Armco is described.

An effective demand-limiting system for the electric furnace steel plant C. A. Scammon (201–212). **Improvement in arc furnace regulation and electrode hoisting systems** F. Nicholson (213–228). **Analysis and practical results obtained from a study of arc-furnace control** J. H. Kogen (229–253) The electrode control systems are shown diagrammatically and analysed as a block diagram. Some components are illustrated. Other points are made in discussion.

Thermocouple control of arc furnace hearth dimensions T. J. Wayne, D. R. Johnson, E. R. Rosenow, and E. J. Whittenberger (*AIMME Elect. Furn. Steel Conf. Proc.*, 1957, 72–82) Six base-metal couples were embedded in inverted-arch subhearths of three basic furnaces and continuous recordings of hearth temperature at the various locations gave information for the maintenance of contours for maximum heat size and eliminated breakouts. **Timken roller bearing results** L. E. Holmes (81–82) An investigation in which resistor-type thermometers were bolted to the bottom plate of a furnace is briefly reported. **Installations at Republic Steel** R. A. Hedin (82–84) An 80-t top-charge electric furnace with an induction stirrer mounted underneath was fitted with twenty resistor-type thermometers to guard against failure. These were unsuccessful owing to corrosion and thermocouples have been substituted.

Oxygen as an aid in electric furnace melting G. Tracey (*AIMME Elect. Furn. Steel Proc.*, 1957, 152–153) Oxygen lancing of scrap in a 3-t, 2000 kva acid-lined swing-roof type furnace making Grade B steel is described. So far the benefits are doubtful. **Oxygen as an aid to melting** L. E. Fink and V. E. Belusko (154–156) Operations at the electric steel foundry are described. Low-carbon Cr-Ni anticorrosive steels are made and advantages are shown. **Some aspects of melting low-temperature high-impact steels** W. A. Koppi (157–165) Steel specifications and melting practice to meet them as carried out by the Lebanon Steel Foundry are briefly discussed. Deoxidation and the minimizing of inclusions are mainly concerned.

Control of electric arc furnace electrodes W. Valachovic (*Ind. Heat.*, 1958, **25,** Sept., 1713–1716; 1893–1900) On the basis of operating data the General Electric Co. of America have developed an automatic electrode regulating system. This employs an amplidyne generator controlling a DC motor and is said to give more rapid response and faster melting.—A. G.

Desulphurization of steel in an induction furnace with direct current O. A. Esin, S. I. Popel', S. G. Bratchikov, V. N. Razumov, and I. M. Plotnikov (*Zhurn. Priklad. Khim.*, 1958, **31,** (12), 1837–1842) It has been shown that for slags rich in sulphur, desulphurization of the steel by electrolysis begins with a cathode density of ~1·5 amp/cm² and of an anode density of ~3 amp/cm². An increase in current density increases the rate of the process. For equal current densities the rate of the process and the completion of the electrochemical desulphurization of malleable steel are lower than for high-carbon steels.

Electrochemical refining and alloying of ferrous metals O. A. Esin, A. I. Kholodov, P. V. Gel'd, and S. I. Popel' (*Stal'*, 1958, *Steel melting processes supplement*, 151–161) Laboratory experiments were carried out in a carbon resistance furnace of magnesite or quartz crucibles in the bottom of which an iron electrode was introduced, and a Silit electrode at the top dipping directly into the slag. In a 50 kg high-frequency furnace with magnesite crucibles, parallel experiments were conducted with a carbon cathode. On a semi-industrial scale tests were also made with 300 kg charges consisting approximately of 210 kg metal and 98 kg slag. In one test with a cathode density of 0·8 amp/cm² in the first 10 min the sulphur content was reduced from 0·036 to 0·028% and remained constant thereafter, the slag being acid. In another, after 8 min the sulphur content was reduced from 0·026 to 0·005% to remain at this level. Experiments have proved that by applying an external electrical field to the metal-slag system, the desulphurization of the steel is considerably more effective than without electrodes.—L. H.

Choosing the frequency of a device for electromagnetic stirring of the metal in an electric furnace G. S. Vainberg (*Elektrichestvo*, 1958, (5), 20–24) The theoretical basis is outlined for an apparatus based on the principle of an asynchronous motor consisting of an arc stator and a rotor formed by the molten metal situated at a considerable distance from it. Frequencies of the order of 5–10 Hertz with the greatest possible surface induction of the stator exerted the greatest torque on the molten metal. Mains frequencies produced inadequate torque.—M. T.

A computer for controlling the working parameters of an arc furnace Yu. E. Efroimovich, A. N. Kotikov, Ya. I. Stiop, E. S. Genishta, and V. B. Tikhmenev (*Elektrichestvo*, 1958, (5), 15–20) It is expedient that the amount of electrical energy fed into an electric arc furnace should fluctuate only inconsiderably from the optimum curve for the variation in the electrical parameters of the furnace during the course of melting, and the minimization of this fluctuation ensures the production of metal of high quality, high furnace output and an economical consumption of electricity per tonne coal. Wiring diagrams are given for the apparatus described, and the full theoretical basis of its operation is outlined. The apparatus was installed to control the electrical input of a 3-phase system into a 20-tonne furnace melting alloy steels, and operated with a maximum error of 2%. The asymmetry of loading of the 3 phases was substantially reduced, and the yearly consumption of refractories fell. The field of metal temperatures was more even, the pouring temperature more accurate, and the melting period was reduced by 5–10%.—M. T.

The minimum ratio of silicon to carbon in killed steel A. M. Levin and A. D. Kramarov (*Stal'*, 1958, *Steel melting processes supplement*, 3–10) Theoretical analysis and experimental data have shown that conditions of deoxidation of the carbon-containing metal by silicon are determined by the ratio Si : C at the temperature of crystallisation. The minimum quantity of Si needed for killing the carbon-containing metal during solidification is determined by the composition of the continuously changing solution during crystallization, when a maximum Si content is removed. With a carbon content of 0·3–1·4% for killed steel the minimum content of Si should remain constant at approximately 0·23%.

Investigation of the decarburizing rate of tubes of 30KhMA steel in a hydrogen atmosphere V. V. Ipat'ev, O.P. Merkulova, and V. P. Teodorovich (*Zhurn. Priklad. Khim.*, 1958, **31,** (12), 1891–1894) Tubular specimens of this steel were heated in electric furnaces between 400–600° at 100–700 atm. pressure of H_2. Chemical analysis of the decarburized layer showed always a residual carbon content of 0·03–0·04%. The results of the experiments can be expressed by a relation between the depth of decarburization and time.

Desulphurization of iron and steel S. L. Gertsman (*Canad. Metalw.*, 1958, **21,** June, 33–37; July, 16–20) The reasons why iron and steel should be desulphurized are discussed and the Kalling process, using a mixture of coke and lime, and the Air Reduction Company process in which CaC_2 is injected into the iron or steel bath in a ladle with N_2 are described. Both processes achieve high S reduction rates, the Airco process is probably the simpler to use. The techniques used in the desulphurization of steel by Mg are described. The direct use of Mg or Mg-rich alloys was either ineffective or too risky according to the method of introduction of the Mg into the steel bath. The injection of a 50% Mg–Al alloy in powder form (–10 mesh) plus lime by carrier gas proved successful.—T. G.

Deoxidation of low alloy steel completely in the ladle I. A. Sokolov, A. N. Vasil'ev, and N. G. Nikulin (*Metallurg*, 1958, (12), 14–17) Additions of Fe-Mn were not used and expensive Mn was replaced with Si-Mn. When the required C, P and S contents were attained the steel was tapped into the ladle to which deoxidizers were added in 2-in. lumps after about one-fifth was filled. Consumption per t was 20–25 kg Si-Mn, 2–2·5 kg Fe-Mn, Mn, 2·5–3·5 kg. (in 6 of the 43 heats only), Fe-Ti 1·2–1·5 kg and Al 0·9–1·0 kg. The steel was held 5–10 min before teeming through a tundish with 33–40 mm nozzles into 6–7 t ingots.—R. S.

The loss of manganese by combustion in deoxidizing rimming steel A. S. Bertsinskaya and T. Sh. Askendaryan (*Stal'*, 1958, *Steel melting processes supplement*, 63–74) In the deoxidation of a number of types of rimming and killed steels, a relation has been established between the loss of Mn by combustion and the Mn concentration in the metal bath before deoxidation. The loss is greater the higher the residual Mn; in rimming steel the loss of Mn by combustion increases appreciably with a carbon content equal to or less than 0·14%. The ratio MnO to FeO in the slag before deoxidation also influences the loss of Mn. This loss is considerably reduced by scattering reducing agents of normal granulation over the whole surface of the bath.—L. H.

The physical chemistry of the deoxidation of steel Chou Yuan-hsi (*Acta Met. Sin.*, 1958, **3,** (3), 238–252) A critical survey of the thermodynamic data. The Fe-O and Fe-C-O systems are considered and the equilibria including such elements as Al, Si, Mn, Cr, V, Ti, B, etc. The deoxidizing power of the elements at 1600°C is compared on a log [%O] – log [%E] diagram. The nature of the products and the reactions occurring in molten iron are also discussed.

The production of ingot moulds from molten blast furnace cast iron G. I. Shandrenko (*Metallurg*, 1958, (8), 10) Although the article by P. V. Gubchevsky, 'Casting Ingot Moulds from Molten Blast Furnace Cast Iron' (1958,

(1) fully indicates the technological advantages of such a production method for ingot moulds, it does not do justice to the economic advantages. At the Krivoi Rog Works with a casting floor area of 10,400 m² it should be possible to produce 100,000 t ingot moulds per annum, in view of the fact that at the Edgar Thomson Works of the US Steel Corp. the output is 250,000 t per annum from a floor area of 8100 m², provided the necessary degree of mechanization is carried out.—M. T.

On the life span of rectangular ingot moulds I. Žadny (*Hutnik*, 1958, **8**, (7), 221–224) [In Czech] Frequent longitudinal cracking of slab-shaped ingot moulds was virtually eliminated by a redesign in which the thermal gradients were minimized. This was achieved mainly by reducing the wall thickness. The weight and capacity of the moulds was of the order of 6 t. —P. F.

Medium size ingot moulds of nodular cast iron A. V. Bobrov and A. A. Sinitsyn (*Stal'*, 1959, (2), 189–191) The life of 1·75 t moulds of Mg nodular iron was 2·19 times that of normal grey iron. The low life of s.g. iron moulds reported in the literature is related to the conditions of use, without heat treatment or with pearlitic structure. The method of inoculation by forced immersion (especially the use of an alloy which economizes Mg and reduces smoke and flash effects) is being perfected and plans for the testing of 6–8 t models of Mg cast iron are being made.—R. S.

Strapping ingot moulds G. I. Shandrenko and N. A. Nikolaenko (*Stal'*, 1959, (1), 94–96) High-C or Mn steel should be used. Correct and incorrect shapes and cross-sections are illustrated and fixing methods are described.

The effect of annealing on 'modified' ingot moulds A. P. Rogach, A. P. Ryzhikova, and D. V. Sklyarenko (*Stal'*, 1959, (1), 92–93) Life was increased by modifying the iron with 45% Fe-Si and annealing the moulds at 500–850°C. This annealing should be repeated after every 100 pourings.—R. S.

Determination of nozzle diameters and pouring rates to be used for top pouring slabbing ingots of rimming steel for deep drawing J. Leclerc and J. Goureau (*Rev. Mét.*, 1958, **55**, Aug., 710–715) Trials are described and the results tabulated in which pouring rates and nozzle diameters are related to the incidence of cracks and splash defects. A rule has been formulated for obtaining optimum nozzle sizes and teeming rates to reduce these defects to a minimum. The formula is correlated with differences in ferrostatic pressure in accordance with ladle capacity.

The effect of pouring conditions on the quality of 5–6 t ingots for plates and of the plates rolled from them G. A. Chikalenko and E. V. Shevbunov (*Metallurg*, 1958, (8), 14–16) When funnel-shaped runner outlet bricks (two per mould) were used for pouring killed steel, examination of a large number of ingots showed that all the surface cracks were the result of high-temperature cracking, some of which were transverse and some longitudinal with reference to the main axis. These were due to the unduly rapid formation of a skin on the top of the metal rising in the mould, as a result of which localized segregations of exogeneous non-metallic inclusions occur. To avoid this the linear pouring rate should be increased or the outlet section of the apertures in the runner outlet bricks should be reduced. Instead of increasing the aperture diameter from 50–60 mm at the outlet, outlet bricks with a uniform internal diameter of 50 mm were tried. This resulted in an overall improvement in the quality of the ingots and the rolled products.—M. T.

Reducing ingot head losses with exothermic mixtures S. Kuběna (*Hutnik*, 1958, **8**, (9), 293–297) [In Czech] The development and application of some new exothermic mixtures, and their use with 4–11-t ingots are described. The use of such mixtures lead to an increase in yield ranging from 5 to 9%. Mixtures consisting mainly of FeSi, with smaller additions of CaSi and iron oxides were found to be most effective.—P. F.

Developments during the last 10–12 years in the sphere of reduction in the size of ingot hot tops E. A. Iodko (*Metallurg*, 1958, (8), 17–20) Various designs of hot-top are considered and the principles governing their reduction in size are outlined. Methods of insulation and heating of hot tops through the use of exothermic materials and electrical arc and induction heating, and pressurization are also discussed.

Variations in hydrogen content during the progress of the heat of transformer steel and the influence of gases on the 'rising' of ingots E. I. Moshkevich (*Metallurg*, 1958, (12), 17–20) It is necessary to dry the O_2 as well as the charge and the Fe-Si and to vacuum treat the metal when decanting from ladle to ladle. Several trials are shown in tables.—R. S.

Speeding up the filling of the feeder head in slab ingots G. A. Chikalenko and T. I. Oleshkevich (*Metallurg*, 1959, (2), 11–13) Usually instructions for teeming are that the head must be filled for the first third at the normal rate of casting of the ingot body and then the feed should be adjusted so that the total time for filling the feeder head shall be not less than half the time of teeming of the body. This has defects, especially with uphill casting. A fall in teeming speed means that colder metal enters the head and the bottom of the ingot has more inclusions. Filling at uniform speed should therefore have advantages. This was tested on 35 casts and data on surface quality are given.—R. S.

The influence of some technological factors on the quality of structural steels used for tyres K. K. Prokhorenko, N. P. Schchekin, and S. M. Sergienko (*Metallurg*, 1959, (1), 11–14) The effect of rate of mould filling on blow hole formation and non-metallic inclusions is discussed; also in relation to longitudinal cracks. The effect of internal mould surface shape on these cracks is also reviewed. Sound ingots were produced with uphill casting at speeds of 12 in/min for 2·5 t ingots bottom poured in small-end-up dodecagonal moulds with feeder heads.—R. S.

Quality of rail steel 9·75 ton ingots S. Ya. Skoblo, E. A. Kazachkov, E. G. Pereverzeva, Yu. I. Kiryushkin, V. G. Strakhov, F. F. Sviridenko, M. T. Bul'skii, and A. G. Alimov (*Metallurg*, 1959, (1), 19) Rail ingot weight was raised from 6·6 metric t at Avostal to increase mill utilization and to accommodate increased OH output. Properties were unchanged and inclusions did not increase.—R. S.

The production of low-Si killed steels J. Chvojka (*Hutnik*, 1958, **8**, (8), 260–263) [In Czech] A significant reduction in the quantity of non-metallic inclusions, and hence in reject rates, is obtainable by decreasing the Si content in round billets of tube steel to about 0·12%, and increasing the consumption of Al deoxidant to 1·2 kg/t. This results in an optimum amount of residual Al in the melt, and reduces the quantity of ferrosilicon required.—P. F.

Variations in the hydrogen content of steel during melting, pouring, casting and solidification K. K. Prokhorenko and E. V. Verkhovtsev (*Stal'*, 1958, *Steel melting processes supplement*, 162–171) Experimental data have shown that the higher the moisture in the fuel oil and the longer the period of charging and melting, the higher the H_2 concentration in OH metal during the finishing period. During refining, the H_2 content increases with the duration of this operation. The variations in H_2 during boiling of the bath are determined by the temperature of the metal. An extension of the preliminary deoxidation of the metal in the furnace results in a sharp increase in H_2; tapping without preliminary deoxidation reduces the H_2 content appreciably.—L. H.

Improving the surface quality of a rimming steel ingot A. G. Nikolaev, Z. I. Ryabov, P. G. Chernogrud, and D. K. Pugachev (*Stal'*, 1959, (2), 123–124) The most troublesome defect at Magnitogorsk on rimming steel ingots for rolling into slabs is scabs. It was decided to take off cuffs during the casting after establishing the maximum permissible thickness of sheets the cuffs from which would dissolve completely in liquid steel and also the best shape and dimensions. Analyses of ½ mm and 1 mm thick sheets are given. Cuffs not thicker than 1 mm dissolve completely and do not form inclusions. (Cuffs, 'manzhet' is the original, appear to be some kind of sleeve.)

The addition of deoxidants and alloying elements in steelmaking K. Protiva (*Hutnik*, 1958, **8**, (9), 297–301) [In Czech] The technology of alloying and the chemical composition of the various additives, such as ferrosilicon, ferrochromium, etc., based mainly on Soviet Standard Specifications, are discussed.—P. F.

Continuous casting of steel in Great Britain (*Machinery Lloyd*, 1958, **30**, Dec. 13, 42–45) A general account of the Low Moor and Barrow plants and various pilot installations.

Twin-strand continuous casting at Barrow (*Iron Steel*, 1958, **31**, Dec., 594) A continuous casting machine at Barrow steelworks has been modified so that twin-strand continuous casting of billets (from 2 to 4 in²) and slabs (up to 12 × 4 in.) is now possible, Normal performance with 2-in² billets is 15 t/h at speeds between 220 and 360 in/min. This is at least twice that of any other known continuous casting process.—T. G.

Twin-strand continuous steel casting at Barrow (*Metallurgia*, 1958, **58**, Nov., 218) A brief account of the modification of the experimental continuous casting machine at Barrow to enable twin-strand casting of billets and slabs to be carried out.

The continuous casting of steel N. Ekwall (*Värm. Bergsmann. Ann.*, 1958, 63–89) The development of continuous casting is outlined, the Nyby Bruks plant and its operation are described, reference is made to the types and production of continuous casting plants throughout the world, and the properties of the cast steel are described.

Shrinking phenomenon in steel blanks by continuous casting V. S. Rutes and V. A. Leites (*Lit. Proizv.*, 1958, (12), 10–12) In the continuous casting of steel into blanks of rectangular cross-section, the shrinkage porosity and resulting defects are reduced to a minimum by the fundamental conditions of solidification. The long sides of the blanks are elastic and little subject to shrinking. At the end of the solidication, the growing crystals join together at the surface and not at the corners, so that the distance for the elimination of heat is shorter than in circular or square blanks.

On the structure of rimming steel ingots M. T. Bul'skii, A. G. Kalashnikov, M. Sh. Beloglovskii, and A. G. Alimov (*Metallurg*, 1958, (12), 20–22) About 60% of the output at Azovstal is rimming steel with up to 0·37%C. Until recently it was supposed to be practically impossible to produce 0·28–0·37%C steel without Si. It is now produced from phosphoric pig iron in large tilting furnaces fired with mixed gas and using O_2 in the flame and through the roof. The steel is bottom poured in small-end-up moulds. Melting and ingot structure are describe.—R. S.

An investigation into the reduction of harmful segregations in rimming steels by blowing oxygen or air into the ingot during solidification Shao Syan-Hua and Puan Yue-Chzhui (*Acta Met. Sin.*, 1958, **3**, (2), 85–98) Tests carried out by blowing compressed air and oxygen into the upper part of the ingot immediately after pouring show that by blowing small amounts of technically pure oxygen into a 7 t ingot of rimming steel during solidification, segregation of carbon, sulphur and phosphorus in the upper part of the ingot has been reduced. Compressed air has the same effect. This is due partly to the oxidizing action of the compressed air or oxygen and partly to the increased effervescence of the metal.—L. H.

Reduction of metal consumption when casting heavy forging ingots V. A. Malyshev, A. F. Gorbachev, and A. G. Papush (*Metallurg*, 1958, (11), 16–18) Electric heating of hot tops results in considerable saving of metal since it is not then necessary to fill up the hot tops. Axial porosity is almost entirely eliminated. Experience in the casting of heavy forging ingots in this way showed that certain difficulties were encountered because of the reduced height of feeder head. In February 1957, the liquid level in the feeder heads was raised and this saved about 6% of the metal per year.—R. S.

On the question of convection diffusion in steels during crystallization L. M. Efimov (*Stal'*, 1958, *Steel melting processes supplement*,

197–202) The approximate value of the actual coefficient of turbulent (convection) diffusion during cooling of killed steel near the solidification point has been determined by means of radioactive indicators. This coefficient defines the diffusion of the element which has been introduced into the metal in liquid phase and indirectly the intensity of the intermixing of the metal in the mould, with an approximation of ± 50%. Thus the numerical value of this coefficient is 50 cm²/sec.—L. H.

Investigating the structure and the crystallization kinetics of the transformer steel ingot by means of autoradiography I. E. Bolotov, V. V. Kurganov, A. A. Popov, A. B. Fedorov, and N. V. Chernikova (*Stal'*, 1958, *Steel melting processes supplement*, 172–183) An aluminium ampoule of molten ^{35}S was thrown into the molten metal in the mould and the sulphur atoms dispersed. Autoradiography reveals the complete picture of the distribution of sulphur in height and cross-section of the ingot. This cannot be attained by any other method. It has thus been established that within the equi-axial zones in the crystals, two types of dendrites exist, one of which has coarse but well-developed crystals and the other only small undeveloped dendrites. The latter type forms owing to the precipitation of crystals in the lower part of the ingot; their presence in these semi-molten masses impedes the penetration of the radioactive atoms.—L. H.

Investigating the rate and sequence of crystallization of steel ingots by radioactive isotopes A. N. Morozov, M. I. Kolosov, A. I. Stroganov, V. F. Isaev, N. V. Keis, and O. Ya. Vainshtein (*Stal'*, 1958, *Steel melting processes supplement*, 203–217) With radioactive indicators introduced into the molten metal in the mould, comparison curves have been obtained parallel with the same data obtained by tipping the ingots. The radioactive indicators make it possible to determine at any instant, during crystallization, the extent of the two-phase regions. Findings show that their thickness at the sides of the ingot during crystallization does not exceed 30–40 mm. After the final formation of the columnar crystals in the lower central section, the two-phase region moves to the upper sections of the ingot. The thickness of the crystallizing layer which includes also the two-phase region is equal to $K\sqrt{t}$ where K is the coefficient for carbon steels fluctuating between 21 and 29 $mm/min^{0.5}$ and t is time of crystallization.

Determining the rate of solidification in ingots of killed and rimming steels by autoradiography A. A. Zborovskii, L. K. Strelkov, M. K. Skul'skii, and Kh. I. Rabinovich (*Stal'*, 1958, *Steel melting processes supplement*, 184–196) Autoradiography of cross-sections of rolled blanks makes it possible to determine with sufficient accuracy the rate of advance of the crystallization front on all sides of the ingot of killed steels, and less accurately in the case of rimming steels. The solidification rate of a rectangular cross section of killed steels is determined by the formula $D = 2{\cdot}6\sqrt{t}$, where D is the thickness of the solidified layer and t, the time.—L. H.

Production of chromium-molybdenum steel V. P. Bondarev (*Metallurg*, 1958, (11), 13–15) Considerable difficulties occurred when producing Cr-Mo steel in 1950 for rolling into 10-in. rounds. Subcutaneous blow holes were found throughout the ingot section either in stringers or as separate pores. In 1957, the plant changed over to the hot charging of ingots and this eliminated the necessity for flame dressing prior to rolling. Details are given of slag control. Ingots were held in the moulds for 2½ h, after which they were charged hot to the blooming mill soaking pits. The Cr-Mo steel produced in small OH furnaces without preliminary deoxidation and cast into 6-t ingots usually had a satisfactory macrostructure.—R. S.

Elimination of surface defects in steel ingots V. A. Efimov (*Stal'*, 1958, *Steel melting processes supplement*, 89–114) The causes of the formation of longitudinal and transverse cracks are studied, as well as the hydrodynamical conditions of pouring into ingots; furthermore, the number of flaws is related to the shape of the pouring spout at the bottom of the moulds. Findings show that longitudinal cracks can occur during filling or immediately after the end of pouring. Both longitudinal and transverse cracks during this period result from the interaction of the ferrostatic pressure and the concentration of the shrinkage stresses. To eliminate longitudinal and transverse cracks it is necessary to avoid crust formation along the whole perimeter of the ingot. This can be attained by selecting optimum parameters for the moulds, by the slowing down of the rate of crystallization during pouring, by properly adjusting the metal jet and by other measures.—L. H.

The factors determining the development of extra-axial chemical non-homogeneity in steel ingots O. D. Zigel', L. I. Morozenskii, and I. Ya. Granat (*Stal'*, 1958, *Steel melting processes supplement*, 75–88) In investigating the formation of ingots, radioactive isotopes ^{32}P, ^{185}W and ^{35}S were used. The findings show that near the crystallization front the molten metal is in motion, the main cause being the shrinkage of the metal in its transition from the liquid to the solid state. The direction of the currents near the crystallization front is determined by the angle of deviation from the horizontal and by the position of the volume of molten metal compensating for the shrinkage.—L. H.

Surface defects in ingots and their products Ingot Surface Defects Sub-committee of BISRA (*ISI special report*, No.63, 1958, Dec., 58) Annotated illustrations are given of all the typical faults, classified into: surface defects present in the ingot, defects in semi-finished and finished products arising from ingot defects, processing defects, and defects in rolled strip.

The influence of the melting process and of deoxidation on the distribution of sulphide inclusions in castings of open-hearth steel S. L. Levin and I. P. Kazachkov (*Lit. Proizv*, 1958, (12), 7–8) Introducing Al into the molten jet at the rate of 400 g/t results in random distribution of sulphide inclusions. Introducing it into the ladle at the rate of 750 g/t together with 150 g and 300 g/t in the molten jet resulted in a stringer arrangement of these inclusions. By introducing a further 300 g into the jet, the stringer formation either disappeared or became smaller.

Study the by radioisotope tracer method (Source of non-metallic inclusions in steel ingots—I) T. Saito (*Tetsu to Hagane*, 1958, **44**, Nov., 1266–1273) ^{45}Ca and ^{95}Zr were introduced into the lining of the ladle and other refractories. The melt contracts during teeming. The non-metallic inclusions were extracted and counted. It was found that about 9% of the total inclusions originated from the refractories. The refractories were the more eroded the higher the pouring temperature, but this eroded material largely floated as ingot scum giving a cleaner ingot in spite of the greater amount of refractory removed than in the case of pouring at a lower temperature.—T. G.

The study of non-metallic inclusions—III The relation between sand marks and the non-metallic inclusions of bearing steel M. Kawai and H. Kimura (*Tetsu to Hagane*, 1958, **44**, Aug., 880–886) More sand marks were found in rods prepared from shrinkage heads than those from the ingot itself. A greater weight of non-metallic inclusions was obtained from a position where the sand marks were clustered. Generally the weight of inclusions at the centre was larger than at the periphery of rods. Non-metallic inclusions existed in the sand marks. Segregation sand marks (caused by P and S) were rarely found in high-C low-Cr steel rod. **IV. The relation between the defects of ingots and sand marks of bearing steel** (*Tetsu to Hagane*, Oct., 1175–1179) The authors then studied the effect of the sand marks on the ingot on the surface quality of the rolled products. The non-metallic inclusions are not only on the surface but also in the interior of the ingot and these cannot be removed by, *e.g.* soaking. The large non-metallic inclusions at the surface of the ingots are elongated during rolling and show up as sand marks on the finished rods.

Studies on the solidification and segregation of larger steel ingots II Observations on the vertical segregation proceeding in the melt by analyzing the metal adhering to the bars during bar-tests H. Morikawa, S. Onodera, and Y. Arakida (*Tetsu to Hagane*, 1958, **44**, Aug., 872–880) Metal adhering to the test-bar used for measuring axial solidification rates was found to reflect the vertical segregation in the melt. This was explained in terms of the upward movement of segregating elements. **III. Behaviour of macro-segregates in the sand-cast ingots solidified with their axes inclined** (Nov., 1259–1265) The moulds for the ingots were inclined at various times between pouring and solidification and the shape and distribution of segregations, particularly the V-shaped segregation, were studied. The nuclei of the V-segregations move towards the vertical after inclination, i.e. there is a definite relationship between location of the V-segregation and the inclination of the mould. Convection in the solidifying melt seems to be negligible.

Relations between chemical variations of molten steel near the solid phase during solidification and chemical segregation in ingots after solidification and defects appearing in ingots. Study on the solidification process of ingots. III S. Maekawa and Y. Nakagawa (*Tetsu to Hagane*, 1958, **44**, June, 650–656) The combination of concentration of elements into the liquid phase and the actual solidification process is likely to produce blowholes and deoxidation products even in steels where these are unexpected. The concentrations formed in the liquid phase can be expressed theoretically, and it accounts for negative segregation in the lower part of the ingot.

Some considerations on the longitudinal cracking of ingots S. Takanashi and S. Iwamura (*Tetsu to Hagane*, 1958, **44**, July, 744–748) Longitudinal cracks in killed ingots are classified in two types. One, found in round ingots with carbon contents below 0·18%, is thought to result from a peritectic reaction; the other, in square-shaped forging ingots with carbon contents above 0·3%, is believed to be caused by heat stress and various stresses associated with the $\gamma \rightarrow \alpha$ transformation.

The effect of some technological variables on yield in the production of seamless tubes from rimming steel V. Friedrich (*Hutnik*, 1958, **8**, (7), 229–233) [In Czech] Yield of seamless tubes is adversely affected mainly by porosity of the steel. It is shown, on the basis of the author's experiments and other data, that by a controlled deoxidation with Mn in the ladle, by a suitable choice of pouring rates and temperatures, as well as by keeping Al additions down to a minimum that the incidence of porosity can be significantly reduced. The reject rate increases approximately linearly with the sulphur content of the finished steel.

PRODUCTION OF FERRO-ALLOYS

Electric-furnace ferro-alloy industry in America J. H. Brennan, H. E. Dunn, and C. M. Cosman (*J. Met.*, 1958, **10**, Dec., 785–789) The development of each of the principal ferro-alloy producers in America is outlined.

Production of ferromanganese: blast-furnace practice in India E. J. Hancock (*Iron Coal Trades Rev.*, 1959, **178**, Jan. 23, 197–200) Indian Fe-Mn is rather high in P and low in Mn due to raw materials composition. High coke rates are necessary and a higher hearth temperature. Furnace operation and control and the outlook for the industry are discussed.

Production of titanium carbide and ferro-titanium from indigenous raw materials G. Socolescu, A. Triandaf, V. Mavromati, and A. Isopescu (*Met. Constr. Masini*, 1958, (10), 847–848) [In Rumanian] The alluvial sands in the Fagaras district consist of ilmenite. They are concentrated in the usual way, by a helicoidal separator, a concentration table and an electrostatic separator to leave behind the SiO_2. The concentrate contains ca. 47–48% TiO_2 as rutile. The concentrate is mixed with Al powder, iron oxide and lime in various proportions calculated on the charge yielding a ferrotitanium with ca. 17·7–22%Ti; 0·1–0·2% C; 1·7–3·5%Si; 3·2–5·8%Al; 3%Cu and 0·02–0·03%S. TiO_2 mixed with carbon black and heated to 1900–1950° during 95–100 min yields titanium carbide with 17·5–18% combined

carbon and 0·05–0·6% free carbon, specific gravity 4·5–4·7 g/cm³.—L. H.

Cleaning ferromanganese gases M. M. Zaitsev, A. I. Makarov, I. L. Tarnavskii, and A. Ya. Tseitlin (*Stal'*, 1959, (2), 181–188) An electro-filter is used after pre-treatment in a tube atomizer at a gas flow rate of ~1·5 m/sec and a resistance in the atomizer of 300–350 mm water-gauge. In spite of the overgrowth of the checkers of the chord scrubber, an open scrubber must be used. A method using 2–3 atomizers for each block is described, each in turn being taken out of the cleaning circuit.—R. S.

FOUNDRY PRACTICE

Arthur Balfour and Co. Ltd. Inauguration of new production facilities (*Brit. Steel*, 1958, **24,** Nov., 352–354) A new high-frequency melting installation is described.

Devices and plant for the degasification of metal melts K. Herfurth (*Giesserei-Techn.*, 1959, **5,** March, 73–77) The following are surveyed: (1) deadmelting, (2) salt treatment, (3) gas scavenging, (4) ultrasonic treatment of melts, (5) vacuum treatment of melts, (6) electrolytic degassing, and (7) filtration of copper melts.—L. J. L.

Foundry materials on the move (*Mod. Castings*, 1958, **34,** Nov., 29–49) A brief survey with illustrations of handling methods at the National Grey Iron Div., Illinois, Auto Specialties Mfg Co. St Joseph, Mich., Minneapolis Electric Steel Castings Co., Ampco Metal Inc., Milwaukee, and Arrow Aluminum Castings Co., Cleveland; followed by sections on hand and power trucks, cranes, fork trucks, skip hoists, conveyors and portable hoppers.

Instrumentation in foundries R. Perlick (*Giesserei-Techn.*, 1959, **5,** March, 69) A few introductory remarks are made on four papers issued by the East German Research Institute for Industrial Development and Metallurgical Heat Technology. The first of these follows. **Measuring the quantity and pressure of blast in cupolas** W. Liebig (70–73) To operate cupola furnaces safely and economically, it is necessary to measure blast volume and pressure. To enable measuring instruments to function, the wind box must be constructed so that blast volume and pressure can be varied at will. Wind boxes must be of different construction for turboblowers and radial cylinder compressors. Measuring instruments must be installed and serviced by experts.

Some problems in the mechanization and automation of foundry production P. N. Aksenov (*Slévarenství*, 1958, **6,** (11), 343–347) [In Czech] A number of problems which have been studied in recent years at the Moscow College of Automobile Engineering are discussed. These include the automatic operation of cupolas, of automatic mould-shakers and squeezers, the design of automatic moulding machines and core blowing machines, the automation of moulding sand mixing, and the filling of the supply bins of moulding machines with sand. Circuits and calculations are considered.—P. F.

Towards automation G. C. B. Lamb (*Brit. Found.*, 1958, **51,** Nov., 549–559) Moulding machines and the layout of integrated machine units, automatic sand control, and distribution and mould shake-out are discussed with examples, and the prospects of developing automatic pouring are considered.

Compressed air ducts in foundries A. Drozd and B. Straus (*Slévárenství*, 1958, **6,** (9), 276–280) [In Czech] The basic principles governing the installation of a network of compressed air ducts in foundries are discussed. These are valid for all foundries; special features must be dealt with individually.—P. F.

A simplified method of working out a formula for the height of the charges in the cupola Y. Szreniawski (*Prz. Odlew.*, 1958, **8,** May, 129–130) A novel and simple method for calculating the height of the charges in the cupola, whilst they remain in a solid state is given.

Direct labour costs cropped 54% by integrated cupola charging W. A. Coakes (*Steel*, 1958, **143,** Dec. 1, 72–73) A general account is given of a semi-automatic charging system.

A mechanism for opening and shutting the bottom of cupola furnaces V. N. Ledyaev (*Lit. Proizv.*, 1958, (8), 10) The mechanism, which is diagramatically illustrated, works on compressed air at 4–6 atm, which operates a ram to raise the bottom after emptying. The bottom is held in place by two catches, which are released by springs as soon as a slight upward movement of the bottom through the action of the ram releases the pressure on the catches.—M. T.

Remarks on certain metallurgical phenomena in the cupola F. Danis (*Fonderie*, 1958, April, 179–182) General considerations on the influence of the blast and of the proportion of coke in the charge, the temperature, oxygen enrichment, carbon content of iron are discussed.

Methods of increasing the output of cupola furnaces and lowering the carbon content of malleable iron Yu. A. Tomilin (*Lit. Proizv.*, 1958, (8), 18–19) A description is given of modifications to the water cooling of two cupola furnaces, reduction of the lining thickness and consequent increase in the internal diameter from 900 to 1150 mm. In the second modification the whole of the upper part of the furnace was encased in a water jacket. To meet the increased capacity the quantity of the blast was increased by a third, and the output of the furnace rose from 5 to 7½ t per hour. To reduce the C content an increased proportion of steel scrap was included in the charge, but the C content remained too high. The second and third rows of tuyeres were then removed, so that the melting zone was reduced in height, the time taken for the molten metal droplets to descend through the maximum temperature zone decreased, and consequently the degree of carburization of the cast iron by solid carbon from the fuel was diminished. In consequence the steel scrap content of the charge was again lowered from 45 to 20%. Carbon content control was then effected by appropriate raising of the consumption of air and increasing the steel scrap content of the charge.—M. T.

On temper iron melted in the basic cupola J. Ptáčnik and Z. Prokeš (*Hutnik*, 1958, **8,** (7), 233–237 [In Czech] Experience with the melting of ferritic and pearlitic temper iron in the basic cupola is discussed. It is concluded that the basic cupola is suitable for melting both types of temper iron. Melting under basic slag affects the fluidity and the graphite particle shape favourably. The cost of melting in the basic cupola need not exceed the cost of melting in the acid cupola.—P. F.

The present state of melting in cupolas with pre-heated blast B. Sochor (*Slévárenství*, 1958, **6,** (10), 305–313) [In Czech] The technical and economic aspects of hot-blast cupolas of various types are discussed with special reference to their utilization in Czechoslovak foundries. The extension of hot-blast methods is urged, particularly where high casting temperatures are required, e.g. for thin-walled castings, or inoculated cast-irons. The conditions favouring the installation of any given type of hot-blast furnace are analysed.—P. F.

The influence of melting technology in the hot-blast cupola on the mechanical properties of ferritic malleable iron Č. Hloušek (*Slévárenství*, 1958, **6,** (12), 71–78) [In Czech] Cast iron was melted in a 5½ ft diameter hot-blast cupola under Ca-Mg, Na and B slags. It was found that the mechanical properties improved with decreasing carbon content. The best mechanical properties were obtained with the usual Ca-Mg slags; the use of Na slags led to a slight decline in the tensile and bend strengths of the iron. Iron melted under boron slags showed a loss in elongation. The low S content of 0·099–0·149%, and that of boron, i.e. 0·0022% present in the iron, did not affect the tempering process at the temperature of 710°C used.—P. F.

Desulphurization of cast iron by magnesium B. S. Mil'man, L. V. Il'icheva, and M. A. Studnits (*Lit. Proizv.*, 1958, (11), 15–17) The problem of desulphurization of cast iron by Mg was the subject of a recent discussion, in which controversial opinions were expressed. Some authors expressed the view that the desulphurization is only apparent, and that overheating of iron results in the return of sulphur to the iron. The tests, which were carried out by TSNIITMASH in order to solve the problem showed that real desulphurization occurred. The tests were performed by using the isotope ^{35}S with a half-period 87·1 days and maximum energy of β-particles of 0·168 MeV. Special attention was paid to a careful separation of slag. Autoradiographs of specimens were obtained. On the basis of these tests the conclusion was reached that incomplete desulphurization was due to redistribution of sulphur between slag and molten iron during overheating.—S. S.

Desulphurization of molten cast iron with magnesium V. I. Lakomskii (*Lit. Proizv.*, 1958, (11), 18) During the tests on desulphurization of cast iron with Mg by using the radioactive isotope ^{35}S deposits of fumes rising from molten iron were investigated. Some authors have found that the fumes contained 50–90% of S in the form of MgS, when the Mg content in grey iron was normal. The author comes to the conclusion that the process of desulphurization takes place on the surface of bubbles of gas and fumes inside the molten iron. The Si and C content in iron increase the activity and contribute to a better removal of S. About 30–40% of S is removed with the fumes, only 40–60% goes into slag.

Cupola grit and dust arresters G. E. Lunt (*Bradley's Mag.*, 1958, Winter, 3–10) A survey of wet and dry spark arresters is given with plans and illustrations and estimates of cost.

Furnace manufacturers: Types and sizes of appliances normally available (*Iron Steel*, 1958, **31,** Dec. 24, 647–662, 686) A survey, based on information supplied by the manufacturers, is presented of the types of melting furnace available in this country.—A. G.

Melting in electric furnaces M. Hájek (*Slévárenství*, 1958, **6,** (12), 384–390). [In Czech] The technological and economic scope of the use of electric furnaces in foundries casting steel, grey cast-iron and non-ferrous metals are analysed. While proper and extensive use of arc furnaces is made in steel foundries, such furnaces are used less and less efficiently in foundries casting grey cast-iron and non-ferrous metals. The decisive factors in deciding for or against the use of arc furnaces in grey iron foundries is shown to be the ratio of the prices of current and coke, and the amount of cheap scrap locally available. Various types of furnaces are illustrated and the technology of melting grey cast-iron in them is discussed.—P. F.

The melting of plain carbon and alloy steels in mains-frequency induction furnaces D. Hartmann (*Giesserei*, 1959, **46,** Jan. 15, 25–30) The development of the mains frequency induction furnace is described and illustrated by examples. This type of unit is compared with other furnace systems; melting losses and steel quality compare well with the more costly medium-frequency induction furnace.

Mains or intermediate frequency furnaces for melting cast iron? Discussion D. Hartmann and B. Marincek (*Electrowärme*, 1959, **17,** Jan, 12–17) A contribution to the discussions on the paper 'The Metallurgy of Cast Iron in the Induction Furnace', by B. Marincek (1958, **16,** Oct. 354–365)

Automatic load control in electric melting furnaces decreases power costs (*Ind. Heat.*, 1958, **25,** Sept., 1728, 1744) A Leeds and Northrup load control system is described which automatically controls the load on melting furnaces in accordance with the most economical power usage. Production is not reduced and furnaces at the refining stage are not interfered with.—A. G.

A suggested new standard for coke pig iron for casting ingots L. I. Gol'denberg and V. S. Monakhova (*Lit. Proizv.*, 1958, (8), 1–3) Extensive liberation of graphitic foam gives rise to more foundry scrap, and to combat this Russian foundries require low-Si casting ingots, which may be produced by using lower blast furnace temperatures. Shortage of Si can be made good by the addition of ferrosilicon. It is therefore suggested that the maximum Si content should be 3·25%, and that a new grade with 0·75–1·25% Si only should be introduced. It is also suggested that the weight

of ingots should not exceed 25 kg., whereby there is an appreciable improvement in quality, owing to greater rapidity of crystallization.—M. T.

The suggested new standard for coke pig iron for casting ingots I. I. Sankov (*Lit. Proizv.*, 1958, (8), 4–6) The author criticises the suggestions and thinks that the maximum Si content should be 3·5% and the minimum 1%. He also considers that C contents should be controlled within the limits 3·5–4·4% as well as those of Si, Mn, P and S. He also suggests that the weight of ingots should be still further reduced to 16–20 kg. He attributes considerable foundry scrap and other losses to the formation of graphitic foam and coarse carbides as a result of failure to limit C contents.

Studies on white cast iron. Eutectic structures of white charcoal irons I. Fukumoto (*Nippon Kinzoku*, 1958, **22**, June, 292–297) A microscopical study is reported on thermically etched samples of white cast iron, cast and heat treated in various ways. **Effect of S on the eutectic structures of Fe-C alloy** I. Fukumoto (297–300) Samples of Fe-C, Fe-C-Cr and Fe-C-Cr-S alloys have been melted in graphite crucibles and cast from 1300°C in an iron mould, a sand mould and a preheated silica tube. Sulphur is stated to accelerate the relative rate of growth of cementite crystals.—A. G.

Remarks concerning gas flushing in the presence of a graphitizing substance and its effect on cast iron structure G. Blanc and N. Volianik (*Fonderie*, 1958, April, 173–174) Experiments have shown that the special conditions of flushing exert a considerable influence on the results. Under certain conditions, the flushing can increase the tendency of the cast iron to solidify in a stable system, i.e. with the appearance of free graphite. Such a result is obtained if a wall of suitable material is placed next to the gas jet and if the agitation produced by the jet is considerable. Such a wall may be a graphite tube through which the gas is blown. A tube of amorphous carbon or silicon carbide has the same effect. This system differs therefore from the method of introducing a powdered or granulated substance by a physical or mechanical process.

Coatings for metallic moulds used for cast iron A. Šustek (*Slévárenství*, 1958, **6**, (9), 280–283) [In Czech] The development of new coatings with a useful life about twice that of coatings hitherto commonly used is described.

Change in characteristics of spheroidal graphite cast iron caused by keeping in molten state after magnesium treatment K. Okabayasi (*Nippon Kinzoku*, 1958, **22**, June, 304–308) The changes observed when remelting spheroidal cast iron after treating with Mg are said to be related to the decrease in residual Mg.—A. G.

Eutecticity as a factor in the technological properties and quality of magnesium cast iron I. F. Kurtov, N. P. Chichagova, and V. A. Zakharov (*Lit. Proizv.*, 1958, (11), 3–4) The use of magnesium cast iron instead of malleable and grey cast iron or steel is of great theoretical and practical interest. However, its use for thin-walled castings requires its heating up to 1450–1500°C, and this leads to intensification of the cupola process or to melting in electric furnaces. These disadvantages can be greatly reduced by using cast iron of eutectic composition. This leads to lowering of temperature, greater fluidity and less porous castings. Castings made from eutectic iron usually have a larger single cavity, which can be kept separate by using a proper riser, whilst there is no simple method of removing porosity. Tests, which were carried out in casting automobile crankshafts, showed that temperatures not exceeding 1410°C gave good results.—S. S.

Crankshafts for diesel tractor motors made from magnesium cast iron A. A. Gorshkov, A. I. Toropov, M. V. Voloshchenko, and K. K. Prozhoga (*Lit. Proizv.*, 1958, (11), 1–3) The heavy operational conditions of Diesel crankshafts are emphasized. Tests, which were carried out in the two Kharkov factories, with crankshafts made from magnesium cast iron gave good results. Some of these shafts have already worked for 3–5 years, their wear resistance is, on the average, greater by 30–40% than that of crankshafts made from forged steel. Fatigue strength also is high. Hollow crankshafts are lighter, their internal structure is good and uniform; the amount and time of machining operations can be reduced by 50%. Moulding procedure is described; various tests before and after machining include γ-ray and magnetic tests.—S. S.

Casting iron parts in metal moulds A. S. Myshkovskii (*Lit. Proizv.*, 1958, (12), 21–22) In 1956 the 'Dnepromet' Plant introduced metal moulds for all cast-iron parts. At present it casts over 150 different parts, some of which are heavy and others are in mass production. Appreciable advantages are claimed for this method and production figures are adduced in support.

Casting permanent magnets into green moulds and dried cores J. Rous (*Slévárenství*, 1958, **6**, (7), 218–222) [In Czech] The technology of casting small magnets into green moulds or into dried thin-walled cores are compared on the basis of works experience. The latter method is shown to be more economical and advantageous.—P. F.

Casting in iron moulds A. P. Prokhorov and N. I. Laskarzhevskii (*Lit. Proizv.*, 1958, (12), 20–21) At the Bobrinsk Plant 77% of the production of stove utensils, pans and weighing machine parts are cast in metal moulds. This method has increased production by 15% and reduced rejects by 38%.

Problems connected with low-silicon foundry irons N. A. Barinov (*Lit. Proizv.*, 1958, (12), 3–6) The two types investigated are SCh 18–36 and SCh 21–40. These are melting in cupolas from blast-furnace irons, conversion pig iron, steel scrap, returns, iron scrap and blast furnace 10% ferrosilicon. The fluidity is satisfactory. The influence of the C and Si content has been investigated and the data obtained are tabulated so that they may be used for selecting the most suitable iron for casting any components or parts.

The new standards for foundry ingot iron L. I. Gol'denberg (*Lit. Proizv.*, 1958, (12), 2–3) Standards are given for six types of irons LKO to LK5 with limits for C, Si, Mn, P and S. A description of the method of production is also given together with the raw materials used in the various plants.

The influence of the time of holding cast-iron in the ladle after modification on its mechanical properties Z. Falecki (*Prz. Odlew.*, 1958, **8**, (8), 221–224) Specimens were taken from four 2·5–2·8-t melts of cast iron, modified with Fe-Si (3·5 mm grain size) at 0·3% of the charge. On the basis of measurements of the tensile and bending strengths, elongation and wedge tests, and metallographic examination, it was established that the optimum pouring time was about 2 min after modification, after which there was a rapid fall in the mechanical properties for 10 min after modification, and thereafter reduction at a slower rate. Simultaneously there occurred an increase in the quantity of graphite with an inter-dendritic orientation, while the basic structure remained unchanged, but it is possible that ferrite may be formed if the interval between modification and pouring exceeds the 30 min period of the tests made. Pouring should start from 2–5 min after modification, and test-pieces must as far as possible be cast simultaneously.—M. T.

Production of black-heart malleable cast iron in the cupola and its rapid annealing Syao Chzun-Gan (*Chinese J. Mech. Eng.*, 1958, **6**, (3), 234–250) Good results have been obtained with a modern cupola by careful selection of the charge and melting process. The article describes also the annealing process in which the graphitization of the first stage was completed within one hour. In view of the increase in the mechanical properties and a reduction in the duration of annealing, the author suggests an increased use of the cupola for the production of this cast iron.

Guiding principles for the design of malleable cast-iron castings Z. Hostinský (*Slévárenství*, 1958, **6**, (12), 79–84) [In Czech] Properties of malleable cast iron, and the design of castings are discussed. In the design the same principles hold as with steel or grey cast iron castings, except for thin-walled castings, when certain changes in these principles have to be maintained and rigorously observed.—P. F.

The theory of tight castings J. Piaskowski (*Prz. Odlew.*, 1958, **8**, (1), 14–16) The author proposes a method of outgassing metals and alloys. The operation can be divided into three stages: formation of liquid oxides on the surface, outgassing by a neutral atmosphere and the introduction of a 'hindering' metal being in a high Pilling-Bedworth's relation and with a stable oxide preventing a secondary saturation with gas during pouring.

The effect of elevated pressure of solidification on the properties of steel and cast iron S. Gebalski (*Prace Instyt. Mechaniki*, 1953, (10), 1–84) Industrial processes and research connected with the problems of increasing the pressure of solidification in the iron and steel casting are surveyed. The apparatus and the method are described in detail. The properties of the steel and cast iron solidified under pressure from 0 to 160 kg/cm² are compared. The effects of pressure on tensile strength, fatigue, hardness, density and other properties were determined. The author concludes that the method of solidification under pressure is quite suitable for both steel and cast iron and that their properties are improved generally.

External chills increase the quality of grey iron castings, and decrease costs K. Hanák (*Slévarenství*, 1958, **6**, (7), 222–225) [In Czech] Through the replacement of sand cores by cast-iron cores in the hubs of grey iron castings improvement in the mechanical properties of the castings were attained. Rejects caused by shrinkage were eliminated, and productivity was increased. Handling is minimized, and cores can be used repeatedly.—P. F.

The technology of casting a 32-ton pressure vessel with a test pressure of 600 atm J. Piechota. (*Prz. Odlew*, 1958, **8**, (8), 225–229) The dimensions of casting were: length 2420 mm, height 2120 mm, width 1900 mm, and the internal diameter of the cylinder 922 mm. The approximate composition of the steel was: 0·32% C; 0·70% Mn; 0·25% Si; 0·020% P; 0·018% S; 0·88% Ni. A full description is given of the preparation of the moulding mixture, the gating system, the preparation of the melt, casting technique and temperatures. The casting was left ten days in the mould and cleaning was carried out with oxy-acetylene torches while still in the mould at a temperature of 300–400°C before completion of cooling. The final structure, after complex heat treatments, was fine-grained and homogeneous, with the following mechanical properties: yield point 34 kg/mm², U.T.S. 51·8 kg/mm², elongation 28·5%, reduction in area 52·5% and impact strength 5·0 kg m/cm².—M. T.

Comparative economy of steel production by the open-hearth and electric furnace in foundry practice N. S. Sachko (*Lit. Proizv.*, 1958, (11), 4–6) The analysis of costs of steel production by these methods is given for various local conditions existing in the Soviet Union. The cost of charge, fuel, wages, maintenance and general costs are considered. Comparative data are tabulated. In nearly all these respects steel obtained from an electric furnace is cheaper, even in the case of a rather high price of electric energy. The author comes to the conclusion that the advantages of steel production by electric furnaces will be even greater in the near future, when the price of electricity will come down, and mineral fuels (oil, coal, peat) will be needed more for the chemical industry. The only advantage of an OH furnace is its ability to produce enough steel for very heavy castings, say 120 t, from two furnaces.—S. S.

Foundry technology involved in the production of castings from Mn-Cr-(Ti) 17/7 steel A. Šustek (*Slévárenství*, 1958, **6**, (7), 214–217) [In Czech] The method of melting austenitic Mn-Cr 17/7 steel used for steam turbines is described, and details are given of the processes of casting, and of testing the castings at high temperatures and pressures.—P. F.

Casting of steel railway wagon wheels in graphite moulds N. M. Smirnov (*Lit. Proizv.*, 1958, (10), 7–8) A description of mechanized casting of railway wagon wheels at the Griffin Wheel Co., USA, taken from *Foundry*, 1957, No.10.—M. T.

An experiment in the use of Chevkassky bentonite in the production of steel castings A. E. Lyutenko (*Lit. Proizv.*, 1958, (10), 31)

To avoid scabbing this material has now been used for over a year under production conditions. A mixture of 80–85% used sand, 18–14% fresh sand and 1–2% bentonite has the following properties: gas permeability 160–200, moisture content 3–3·5%; dry compression strength 0·35–0·45 kg/cm². The core mixture contains 45–50% used sand, 50–46% fresh sand, 4–5% bentonite and 0·5–1% of sulphite waste liquor (dens. 1·1–1·2) with mechanical properties: gas permeability 160–200, moisture content 4–4·5%, dry compression strength 0·40–0·50 kg/cm². Bentonite in powder form gives good results as swelling of its grains hardens the mixture during ageing, but in the absence of facilities it can be used in paste form. After painting with marshalite, cores are dried at 150–200°C. Cores were easily knocked out of the castings which had an improved skin, resulting in a marked reduction in fettling time. Bentonite obviated the use of refractory coatings on moulds and cores.—M. T.

Phosphide porosity in iron A. A. Timofeev (*Lit. Proizv.*, 1958, (12), 17–19) Increasing the temperature interval of solidification by the phosphorus content of low-carbon iron has a great influence on its porosity and air-tightness. Tests were carried out on cast iron of different compositions related to the carbon equivalent (which was taken as the usual carbon content + 0·3 Si). The metal was melted in an induction furnace and poured in four different ways, each time into one mould containing three specimens at 1300 ± 10°. After each pouring and reheating, 15% Fe–P was added to obtain the requisite percentage. The specimens were tested for air-tightness at 800/900 atm and results of the tests are set out.

Correspondence on the paper: Some experiments on the cause of peeling in whiteheart malleable cast iron (*Brit. Found.*, 1958, **51,** Nov., 591) In the discussion on the above paper (*ibid.*, 1958, **51,** Sept., 457), the subject of the substitution of limestone for hematite ore as an oxidizing agent was discussed; in the present correspondence E. Longden emphasizes that the use of limestone in this way has been shown to be satisfactory, and that failure by the fusion of limestone was not visualized by him. The cost of indigenous limestone is so low that it would compare favourably with ore, in spite of losses by powdering, and the additional work of handling the rejected fines.

Dark stains on the surface of soft cast-iron rolls R. Kamensky and L. Toman (*Slévárenství*, 1958, **6,** (7), 210–214 [In Czech] The spots were found to be a consequence of segregation, favoured by the low carbon content. Modifications in the preparation of the melt, to minimize its gasification, and changes in casting and chilling, to increase the rate of cooling, are recommended to overcome the occurrence of these defects.—F. F.

Further remarks on the hot cracks in steel castings G. Kniaginin (*Prz. Odlew.*, 1958, **8,** May, 121–129) Scope and causes of hot cracks are discussed. It is emphasized that in the formation of hot cracks not only the resistance to the casting contraction inherent in the mould and core is of greatest importance, but above all the dilatability of the moulding and core sands over the range of temperatures at which these cracks form. The most efficient way for preventing hot cracking is cooling of the outside parts which are most likely to develop them.

A contribution to the problem of pinhole porosity (sub-surface blowholes) in steel castings F. Brunn (*Giessereitechn.*, 1958, **4,** Dec., 307–310) The author develops a theory of the formation of sub-surface pinholes in terms of hydrogen diffusion.

On the shrinkage of inoculated irons L. Sofroni and C. Cosneanu (*Studii si Cercetari de Metalurgie*, 1958, (4), 439–450) The critical range (corresponding to that content of Si for which the iron becomes structurally sensitive to small variations in the Si content) is around 1·76% Si. The large variations in linear shrinkage and in the volume of pipe correspond to an increase in the Si content. In white pig irons, where the amount of eutectic and subeutectic graphite is small, the volume of the pipe is large while the initial dilatation is practically zero. In irons ranging from a mottled structure to a properly inoculated iron structure, the initial and eutectoid expansions increase with the quantity of inoculant and of silicon, and the initial and ante-pearlitic shrinkage is reduced.

Ways of increasing safety in foundries J. Širokich (*Slévárenství*, 1958, **6,** (11), 348–353; (12), 379–384) [In Czech] Measures for the prevention of accidents and the maintenance of the highest standards of safety and hygiene are discussed. Precautions required in mechanical handling, and the prevention of detrimental effects arising from noise, air pollution, vibrations, etc. are discussed in detail, with reference to specific foundry operations. The effects of automation and mechanization, particularly as potentially safe modes of work, are considered.—F. F.

VACUUM METALLURGY

Selection of pumping systems for vacuum metallurgical processes A. S. D. Barrett and M. E. Harper (*J. Inst. Met.*, 1959, **87,** March, 227–234)

Vacuum melting (*AIMME Elect. Furn. Steel Proc.*, 1957, 92). **Overall summary of vacuum melting** C. T. Evans jun. (93–110) A review of experimental and industrial vacuum melting methods and installations in the US and their capacities and uses is given. The Inductovac, Duomelt and other arc processes are discussed in further detail and their effects on steel and non-ferrous metals are noted. Comparisons with air melting processes are made. **Consumable electrode vacuum arc melting** H. Gruber (110–124) Furnace design and operation is reviewed, mainly for Ti and Zn. **Outlook for development of vacuum arc melting techniques** (127–128). **Application of process and metallurgical results** (129–132) (23 refs.) **Induction vacuum refining and melting** E. S. Machlin, F. N. Darmara, and P. W. Beamer (133–141) The physical chemistry and thermodynamics are sketched and the cases of deoxidation and desulphurization are evaluated.

Timken goes to vacuum melting (*Iron Age*, 1958, **182,** Oct. 23, 64–65) A brief description is given of a consumable electrode vacuum arc furnace installation. After manual adjustment and striking of the arc, control of melting is automatic. Maximum ingot weight is 5-t and monthly output is 200-t.—A. G.

Vacuum melting and heat treating – Vacuum heat treating R. R. Giler (*Ind. Heat.*, 1958, **25,** Nov., 2236–2248) A description is given of vacuum heat treatment furnaces incorporating water-cooled retorts to prolong retort life.

Degassing of steel in a vacuum M. Nakatsukasa (*Tetsu to Hagane*, 1958, **44,** July, 768–778) [In Japanese] A review, with nineteen references.—K. E. J.

Vacuum treatment of acid Bessemer steel A. M. Samarin, L. M. Novik, G. E. Tsukanov, M. P. Kuznetsov, and A. I. Lukutin (*Stal'*, 1959, (3), 231–238) Treatment in the ladle brought the quality up to that of OH steel. With 14–15 min treatment at 5–10 mm for killed and 15–20 mm for rimming steel extensive degasification was achieved. (O_2 fell to 0·0013% for rail steel and to 0·0014% for rimming steel.) H_2 fell to less than half (2 c.c./100 g and 2·4 c.c./100 g respectively) and N_2 was reduced by 38·5%. This obviates slow cooling, isothermal annealing, and Al deoxidation. The steels were more ductile at high and low temperatures and after ageing. With 0·8% C and 0·1–0·2% V or 0·003–0·005% B or 1·2 kg/t Ti with subsequent normalizing, non-ageing rails superior to OH rails were obtained. Welding properties were also enhanced.—R. S.

REHEATING FURNACES AND SOAKING PITS

The philosophy of soaking pits W. Trinks (*Ind. Heat.*, 1958, **25,** Sept., 1732–1734) The relationship between the time before stripping an ingot and the soaking time necessary is examined. Reduction in pit area and by placing ingots closer together is not considered feasible since gas flow between the ingots would be too rapid for proper heat transfer.—A. G.

Increasing the efficiency of soaking pits Z. Volf (*Hutník*, 1958, **8,** (7), 225–229) [In Czech] Factors influencing the efficiency of soaking pits are considered, and their mutual interrelation is discussed.—F. F.

Experience in the operation of recuperative soaking pits M. E. Boiko, V. S. Gulunov, I. M. Ezikov, M. M. Prikhodchenko, and N. M. Sakharova (*Stal'*, 1959, (2), 170–175) With dry removal of slag a thin coke cushion 6 in. deep is necessary, and forced working must be restricted to economize fuel and protect the checkers. Building up of the hearth even with mechanized slag removal, involves many stoppages for repair and heavy physical labour. A method of operation is described with continous liquid slag removal and a mixture of coke, sand and lime is used to fettle the bottom. Productivity was raised, fuel consumption lowered, and refractory life improved. In a slightly acid atmosphere metal losses by burning were reduced by 30% and continuous liquid slag removal was achieved.

Short flame high pressure nozzle V. D. Esipov (*Metallurg*, 1959, (2), 28–31) A redesigned burner for a sheet mill batch furnace for reheating 5·5 t slabs is described, burning blast furnace or coke oven gas. Maximum furnace heat input is $7{\cdot}5–8 \times 10^6$ kcal/h from 10 burners, 5 on each side. The burners are described and illustrated and are designed for 'twin straight jet atomization'.—R. S.

Bloom reheat furnace of continuous type minimizes hot steel handling (*Ind. Heat.*, 1958, **25,** Sept., 1736, 1744) A continuous bloom reheating furnace is described consisting of nine barrel-type units, which accepts a cool bloom whenever space is available. A capacity of 198 t/h is claimed with savings in scale loss and floor space.—A. G.

High temperature conveyor furnace for heating steel blanks (*Ind. Gas*, 1959, **22,** Mar., 16–17) Blanks for stamping are heated and delivered to a single-process machine at 180 per h. The working chamber of the furnace is $5\frac{1}{2} \times 6\frac{1}{2} \times 26$ in constructed of sillimanite.

Forge furnaces with protecting atmospheres for small forgings L. V. Podgurskii (*Vestnik Mashin.*, 1955, (4), 38–40) A description is given of various furnaces, muffle and electric, fitted with a cracking generator consisting of three sections, a cracking chamber where fuel and air are incompletely burnt, a cracking generator placed in this chamber, through which the incompletely burnt products pass connected with the heating muffle by a tube filled with charcoal heated to 1200° which acts as an active filter absorbing carbon dioxide, steam and oxygen.—L. H.

Economy in heating billets for forging (*Metallurgia*, 1958, **58,** Dec., 288) A Birlec dual-frequency induction furnace installed at the works of Forging and Presswork Ltd for heating billets works at mains frequency for preheating to 700°C and at 3 kc/s for final heating to forging temperature.

Investigation of ingot reheating in a battery of soaking pits supplying a slabbing mill J. Leclerc and J. Goureau (*Rev. Mét.*, 1958, **55,** Aug., 697–709) A series of long-term trials is described, in which the temperature changes in ingots charged cold or hot into the pits was investigated. A formula relating ingot thickness and heating time was derived, track times being later taken into account.

New high frequency induction equipment for heating billets for rolling J. C. Howard (*Metallurgia*, 1958, **58,** Dec., 270–272) A description is given of the operation of a high-frequency induction billet heating furnace installed at the Crawley works of Telegraph Constructions and Maintenance Co. Ltd, to avoid sulphur contamination in heating a wide range of alloy billets.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Automatic batch furnace cuts costs (*Can. Metalw.*, 1958, **21,** Sept., 20, 22, 24) A concealed-quench automatic furnace for hardening and other processes is described. Loading and unloading are automatic.

Mechanized heat treatment (*Auto. Eng.*, 1958, **48,** Sept., 362–363) An account of the Firth–Derihon Stampings Ltd plant at Darley Dale.

Universal heat-treatment furnace (*Iron Steel*, 1958, **31**, Nov., 549–550) An account of the design and operation of a large furnace for the stress-relieving of large welded fabrications.

Indirect gas fired furnaces for high temperature processes A. H. Koch (*Ind. Heat.*, 1958, **25**, Nov., 2252–2264) Heat-resistant materials often require high temperature treatment during their production, e.g. brazing, sintering, high temperature carburization. The requirements of these processes are discussed together with the indirect fired furnaces used to meet them.—A. G.

A universal furnace P. I. Shashkin (*Vestnik Mashin.*, 1955, (12), 61) This furnace has been evolved for the repair shops of tractor stations and collective farms. It consists of four chambers. In the lowest the fuel is introduced through a nozzle, where it burns at ~ 1300°. Above it is the main working chamber used for heating the metal under treatment. From here the gases enter the third chamber where their temperature falls to between 650° and 700°. This chamber preheats the parts before their introduction into the main working chamber, and the fourth chamber has its muffle. Drawings and measurements are given.—L. B.

Development and production of the controlled atmosphere furnace by Kepston Ltd (*Techn. Inf. Library Services, Ministry of Supply, S and T Memo. No.* 12/58, 1958, Sept., pp. 63 + plates) Development of a furnace for the copper brazing of mild steel is described and tests on the joints are quoted.

A method of studying the influence of flame characteristics on heat transfer in furnaces A. M. Godridge, G. G. Thurlow, and J. Wallis (*J. Inst. Fuel*, 1958, **31**, Nov., 491–505) A small-scale apparatus is described and data are obtained which can be applied to full scale plant with confidence.

Luminous-wall firing: Low-cost idea in rapid heating (*Iron Age*, 1958, **182**, Dec. 4, 127–129) The performance of a 30 ft long 'luminous wall' furnace used to solution-treat stainless steel tubing is described. A gas-air mixture is forced through the porous lining of the furnace and burns on the inner surface. One of the important characteristics of the method is the rapid heating and cooling cycle possible; only the surface of the brickwork is heated and the heat storage in the bulk is kept to a minimum. Heat transfer is largely by radiation. Fuel costs were cut by 60% compared with the previous method.—D. L. C. P.

Heating capacity of nitrate baths P. Ya. Yakovlev (*Metallov. Obra. Met.*, 1958, (10), 47–50) The heating capacity of nitrate baths decreases with their age. The regeneration of the salts requires periodical additions of anhydrous barium nitrate as determined by chemical analysis. NaCl, KCl, NaOH and KOH must not be used since they increase the chemical activity of the nitrate medium and accelerate the ageing of the bath. Sodium nitrite must not be used for high temperatures (450–520°) because of its instability but is recommended for temperatures between 200–300°. Eutectic $NaNO_3$–KNO_3 composition is recommended for work at 200–300°; at 450–520° the composition is unimportant, but frequent sludge removal is advisable.—L. B.

High temperature work baskets used to improve economy in heat treating operations (*Ind. Heat.*, 1958, **25**, Nov., 2228–2232) A specially designed heat-treating work basket is described which has proved advantageous in practice. It is entirely made of Inconel and has strength, long life and adaptability.—A. G.

Heat treatment of instrument and high speed steels in a steam atmosphere A. P. Gulyaev, Z. S. Luneva, G. G. Korolev, and V. V. Samoilov (*Metallov. Obra. Met.*, 1958, (11), 39–44) Experimental results have shown that this heat treatment is advisable as an additional treatment for boring and grinding tools to increase their anti-corrosion and cutting properties and as an atmosphere for the furnace to protect the surfaces of the tools from corrosion without an intermediate chemical operation being necessary. In treating with steam between 500–600° a dense layer of Fe_3O_4 is formed of a thickness of a few microns (1–4μ) which results in increasing the temperature of adhesion of the metal in work by 100–150°. The steam treatment does not impair the cleanliness of the surface when heated in a bath of potassium nitrate, or in air, which is of importance for the service life of the tools.

Isothermal transformation diagram on heating SG iron D. Rasheev (*Metallov. Obra. Met.*, 1958, (10), 5–10) Isothermal transformation diagrams are plotted for SG iron (2·7% C, 2·7% Si) with initial pearlite, ferrite and mixed pearlite-ferrite structures. Use of diagrams for establishing suitable heat-treatment conditions is discussed.—L. B.

Some examples of heat treatments for steels used for high-pressure ducts V. Vondrášek (*Sbornik, Ostrava*, 1958, **4**, (2), 125–134) [In Czech] Microstructures developed in a cast 0·56%C steel in the as-cast state, and after various heat-treatments were studied. On the basis of this a rational method of heat-treating cast pressure ducts is proposed.—P. F.

Structure, properties and heat treatment of high speed steels Yu. A. Geller and V. S. Kachanov (*Metallov. Obra. Met.*, 1958, (11), 6–19) A comparative study of American and Soviet Co, V and Co-V steels is reported.

Heat treatment of structural low carbon steel O. L. Petrov (*Stal'*, 1959, (1), 81–85) These steels must be quenched from 920°C in water and tempered at 450°C with a holding period in the quenching bath at about 16°C. The advantages of this treatment are stated.—R. S.

Quenching in water air mixtures M. E. Blanter, N. A. Kulakov, I. M. Sergeichev, T. A. Mikhin, and S. D. Fainbron (*Metallov. Obra. Met.*, 1958, (12), 29–34) The quenching properties of water–air mixtures vary within wide limits; cooling in oil is equivalent to cooling in air with a low moisture content, i.e. with a water consumption of 20 l/h. It was found experimentally that the optimum distance between the spray nozzle and the cooling surface is approximately 500 mm with an optimum pressure of 3 atm.

Quenching in streaming mineral oil under pressure P. Csokán, L. Berán, and G. Albrecht (*Stahl Eisen*, 1959, **79**, Jan. 22, 102–104) The principles of quenching of thick-walled pipes are reviewed and a device is described in which quenching oil is forced at a pressure of 3–4 atm, corresponding to a velocity of 10 in./sec, over the surface of the tube. Quenching from 850 to 100°C takes about 4–5 min because of the low thermal conductivity of the metal in the interior of the tube wall. It was found that turbulent flow gives higher cooling rates than laminar flow.—T. G.

Determination of the index of severity of hardening H of a quenching liquid. Standardization of conditions of hardening on test pieces J. Phéline (*Centre Doc. Sidér. Circ.*, 1959, (1), 213–223) The hardening severity characteristics in oil are determined for steel $35CD_4$, and the influence of hardening conditions on the preparation in a standard state of test pieces of steels 16 NC 6 (soft grade) and $35\,CD_4$ (medium hard grade) is assessed.

Changes of cooling ability with the oxidation and polymerization process of oil. On the deterioration of quenching oils. IV M. Tagaya and I. Tamura (*Tetsu to Hagane*, 1958, **44**, June, 668–673) Cooling ability increases slightly in the induction period of oxidation and polymerization, and increases progressively in the peroxide formation period, decreasing gradually in the peroxide decomposition period and rapidly in the polymerization period. Other properties are related to the oxidation process. Graphical methods can be used to predict the life of oils and the variation of cooling ability as they deteriorate.—K. E. J.

Deformation of quenched steel surfaces Yu. M. Bogatyrev and V. P. Eremina (*Metallov. Obra. Met.*, 1958, (12), 35–41) An increase in temperature for quenching results in an increase in deformation but does not influence the nature of this deformation. The greatest effect of an increase in temperature is the change in the internal and external diameters and, to a lesser degree, in the height of the specimens. The greatest quenching deformation occurs with water, the least with oil. Addition of 30% glycerine solution and 5% $KMnO_4$ solution slightly reduces deformation but is very effective in preventing crack formations.

Isothermal transformation and structural constituents after quenching. (Hot-bath quenching of a low W–Cr tool steel (8KS 2) in the low temperature range—I) I. Tatsukawa (*Tetsu to Hagane*, 1958, **44**, Nov., 1279–1283) Hardness and microscopical tests and dilatometric and magnetic analyses were used to study isothermal transformation and phases after hot-bath quenching below the Ms temperature in order to improve the properties of a tool steel containing 1·0C, 1·0Cr, and 1·4%W. The results of the tests are presented as graphs.

Effect of internal transformation on stress relaxation in tempering of 30KhGSNA steel and in ageing V95 alloy A. A. Gol'denberg (*Metallov. Obra. Met.*, 1958, (10), 11–17) Internal transformation in 30KhGSNA steel (0·3%C, 1·06%Mn, 0·85%Si, 1·2%Cr, 1·7%Ni) and V95 Al alloy increase the stress relaxation rates. An increase in temperature shortens the relaxation processes and lowers the level of residual stresses.—L. B.

Carbide segregation during tempering of alloy steels. A survey of British and American papers (*Metallov. Obra. Met.*, 1958, (7), 59–61).

FORGING, STAMPING, DRAWING AND PRESSING

Forging crankshafts by the CGF process J. F. Pertree (*Vickers Mag.*, 1958–59, Winter, 11–12) The continuous grain flow process is outlined as operated by the English Steel Corporation.

The relation of forgeability and cast structures of Timken 16–25–6. (On the forgeability of the transformation-free alloy ingot—I) G. Mima and T. Yamane (*Tetsu to Hagane*, 1958, **44**, Oct., 1170–1175) Samples of this steel having columnar, granular, and a mixture of both structures were forged at 800–1 300°C and resistance to deformation, deformation rate, and the sensibility to crack formation were studied. The results are presented in graphs with captions in English.—T. G.

Increasing the forging temperature of 25 and 43N structural steels M. P. Braun, N. I. Kon, and E. I. Mirovskii (*Metallov. Obra. Met.*, 1958, (10), 41–46) As a result of tests it is recommended that forging temperatures of the 0·23%C steel should be raised from 1 150° to 1 270–1 280° and that of 0·43%C, 1·2%Ni steel to 1 250–1 260°. The resulting coarse structure is refined by plastic deformation and subsequent heat treatment.—L. B.

Influence on the final forging temperature on the mechanical properties of forgings I. G. Generson (*Metallov. Obra. Met.*, 1958, (8), 46–51) Turbine and compressor discs are now forged from 40N steel (0·45%C, 0·96%Ni) with the final forging temperatures raised to 1050–1 080° and with intermediate heating of formed parts to 1 050°. Investigations on an industrial scale confirm that discs forged at these temperatures are equal in mechanical properties to discs forged at much lower temperatures.

Increasing the strength of steel parts by torsion B. V. Panov (*Metallov. Obra. Met.*, 1958, (10), 50–56) Work hardening increases the strength of steel parts even when the residual stresses are tangential and the working stresses normal. Torsional cold working is as effective as shot-peening and roller surface working. The treatment is effective even in the presence of stress raisers, e.g. when holes are drilled or the part is treated, and is recommended where the use of alloy steels is to be avoided and heat treatment is not indicated.

The largest pressing facility yet (*Can. Metalw.*, 1958, **21**, Aug., 52, 54, 56) An account of a press of 4 500 t capacity handling plates 25 × 10 ft being constructed for Whessoe Ltd by Fielding and Platt Ltd is briefly described.

Recent investigations into the blanking and piercing of sheet materials R. Tilsley and F. Howard (*Sheet Metal Ind.*, 1958, **35**, Nov., 817–828) Recent work on some of the factors affecting the blanking and piercing operation is discussed in relation to the requirements of the presswork engineer. Points demanding further investigation are indicated.—A. G.

Automatic press for small forgings (*Metal Progress*, 1958, **74**, Nov., 116) A new automatic forging press for mass production of parts such as connecting rods, stem pinions, ring gears, track links and wheel hubs is described. At

each stroke of the press, a forging operation is effected at each station and the part advanced. Up to 40 strokes per min are possible.

Improving the technology of producing small pressings in sheet steel L. G. Kovtun (*Vestnik Mashin.*, 1958, **38**, (10), 52–54) The use of a flange on small pressings facilitates drawing at low pressures and reduces the number of draws. The effects of inter-stage annealing are also considered.—M. T.

The influence of the tool shape and degree of deformation on strain distribution in pressed steel billets Yu. F. Chernyi (*Metallov. Obra. Met.*, 1958, (8), 51–56) Grain size distribution in heat-resistant steel and technical grade iron, hot extruded through various types of matrices was determined. The greatest deformation heterogeneity was observed in the peripheral zones of the billet. The degree of deformation in the surface layer was smaller than in the adjoining layer in which it reaches a maximum.—L. H.

Progressive cold forming (*Auto. Eng.*, 1958, **48**, Sept., 336–337) A brief account of machines made by F. B. Hatebur of Basle for bolt heading and nut forming is given.

Investigation of new stamping steels for the hot stamping of heat-resistant alloys A. P. Gulyaev, S. L. Rustem, G. N. Orekhov, and G. P. Alekseeva (*Metallov. Obra. Met.*, 1958, (7), 2–10) Fifteen steels were tested at elevated temperatures. Four types of steels are recommended: (a) 0·35–0·45C, 1·2–1·4Si, 6·0–7·0Cr, 0·5–0·6V, 6·0–7·0W and three containing: 0·3–0·4S, 3·0–3·5Cr and, (b) 0·4–0·6V, 8·0–9·0W, 1·0–1·2Mo, (c) 1·5–2·0V, 2·0–2·5W, 2·0–2·5Mo and (d) 0·5–0·7V, 1·0–1·5W, 5·5–6·0Mo.—L. H.

Forming metals at high velocities T. C. DuMond (*Met. Prog.*, 1958, **74**, Nov., 68–76) The principles, practice and applications of high-energy-rate or explosive forming are described. The method is being increasingly used; a major advantage is the possibility of forming large parts in tough metals almost impossible by other methods, but the low die and equipment costs make it attractive in other cases. Diagrams are given to illustrate eleven variations of the process. Operations possible include dimpling, bulging or necking hollow parts, embossing, perforating, slotting.

Rapid countersinking in sulphur iron V. F. Afanas'ev (*Vestnik Mashin.*, 1959, (9), 32–44) Experiments are described regarding the effect of various factors on the wear and resistance of countersinking and on the torque and the axial force in rapid operations on a sulphur iron of the following composition: 2·9%C; 1·5%Si; 0·93%Mn; 0·182%S; and 0·24%P. Strength between 195–215 kg/mm². Countersinks were made with hard alloy VK8 and the conditions of the experiments were; rate 6·8 to 125·1 m/min, depth of cut 0·5–4·0 mm and feed between 0·11 to 11·6 mm/rev. A special geometry is recommended for the cutting tools.

Drawing of steel 114260 M. Prouza (*Hutník*, 1958, **8**, (8), 278–280 [In Czech] The technology of drawing a steel used for springs subjected to heavy working conditions in road and rail vehicles, and containing 0·5–0·6%C, 0·5–0·8%Mn, 1·3–1·6%Si, 0·5–0·7%Cr, 0·035%P max., 0·035%S max., is described.—P. F.

Improving the process of deep-drawing stainless steel B. Ya. Ketslakh (*Vestnik Mashin.*, 1955, (11), 51–52) An investigation into the main factors influencing the quality of the products; selection of the method for hardening the working surfaces of dies and avoidance of the adherence of particles from the drawn metal, selection of the most effective lubricant, determination of the optimum clearance between die and mandrel, etc.—L. H.

Improving the cold-drawing of tubes with a long movable mandrel L. E. Al'shevskii (*Stal'*, 1958, *Rolling and tube production supplement*, 352–369) A method is described of organizing the cold drawing so as to produce in three passes tubes 40 × 1 mm from initial dimensions 57 × 3·5 mm against the old method which required four passes for the same reduction. The drawing coefficient is 2·36 against 2·77 and the specific consumption of material is 1·125 against 1·25 with the original process.

On the deep-drawability and anisotropy of mild steel sheets T. Mitsuhashi, K. Kimura, and Y. Hosoi (*Tetsu to Hagane*, 1958, **44**, July, 749–754) Results are given for Armco, Al-killed and rimmed steel sheets. Generally Armco sheet had the best deep-drawing properties and rimmed sheet the worst; these correspond to the degree of anisotropy. Anisotropic effects were destroyed by heating at 950°C for 20 min, and this is probably related to pptn of AlN. Rimmed sheets did not display anisotropy. (12 references).—E. E. J.

The drawing force in the cold drawing of tubes with a zinc phosphate layer M. A. Freiberg and V. I. Moskalenko (*Stal'*, 1958, *Rolling and tube production supplement*, 370–377) Experiments have shown that a zinc phosphate layer gives much better anti-friction properties than a copper layer. The friction coefficient of the zinc phosphate layer is 0·08–0·1. Verification of the calculated drawing forces have made it possible to improve a number of sizes by cutting out one or two passes.—L. H.

The effect of some factors on the quality of deep-drawing sheet B. Otta and J. Teindl (*Sbornik, Ostrava*, 1958, **6**, (5), 391–406) [In Czech] A report is made on detailed researches carried out by the authors on the effect of composition and all phases of process technology on the drawability. Deoxidizing the steel with ZrSi and with CaSi was also studied.

Sheet thickness and steel purity assessed by deep drawing B. Otta and J. Teindl (*Sbornik, Ostrava*, 1958, **4**, (2), 117–119) [In Czech] A statistical analysis of reject rates in deep drawing of steel sheet shows that a linear relation of the form $y = ax + b$ between the reject rate y, and the sheet thickness x exists. The parameter b is a measure of the purity of the steels, the impurity content being the second parameter of greatest importance in determining y. Deep drawing tests are suitable for the determination of a and b, the drawability constants x, for any given type of sheet investigated. The relation is particularly useful for purposes of comparison of drawability at various stages in the production of sheet.

Draw die forms tapered parts C. Myers (*Iron Age*, 1958, **182**, (15), Oct. 9, 86–87) A draw die is described having movable segments operated by a constant pressure hydraulic system. The die maintains a constant ironing and trapping pressure and assists in the production of tapered parts to close tolerances.—A. G.

Technological calculations of the process of multi-stage drawing of high square and rectangular boxes V. P. Romanovskii (*Vestnik Mashin.*, 1958, (12), 38–42) Calculations are given for three methods of multi-stage drawing of square and rectangular boxes. One in which all operations have cylindrical punches and only the last gives the square shape, the second method in which the first and sometimes the second operations are of square form with wide corner angles, and a third method in which the first and second operations give a rectangular shape with small curvature of the sides.

Phosphatization facilitates cold working of steel K. Kapitanczy and Z. Kurzawa (*Prace Inst. Mechaniki*, 1955, **5**, (15), 67–72) The theoretical basis of phosphatizing, its advantages and the possibilities of its application in deep-drawing are discussed. The technology of the surface preparation is described. Results of investigations of bonderizing and drawing steel sheets are tabulated.

High-speed piercing method slashes short-run costs E. J. Egan jun. (*Iron Age*, 1958, **182**, Oct. 23, 73–75) For the accurate piercing of different hole shapes and sizes in a small number of sheet metal blanks, a turret punch is recommended. Quick change punches and dies may be mounted in up to twenty turret stations.—A. G.

Some problems in the manufacture of wrought semi-finished products O. H. C. Messner (*Sheet Metal Ind.*, 1958, **35**, Nov., 829–845, 848) A comprehensive account is given of the equipment and problems involved in the processes of hot and cold rolling, deep drawing, extrusion and rod and tube drawing.—A. G.

Semi-continuous wire mill in the VEB steelworks and rolling plant, Brandenburg E. Kunzmann and K. Böhle (*Neue Hütte*, 1959, **4**, Feb., 100–106) The equipment and operation of the mill are described.

Henry Wiggin and Co. Ltd. Complete first stage of Hereford expansion (*Sheet Metal Ind.*, 1958, **35**, Nov., 846–848) A description is given of the facilities now in use at Hereford. These comprise melting and metal recovery, machining, extrusion, hot and cold rolling maintenance, inspection and stores.—A. G.

Cold extrusion for high temperature metals R. Quadt (*Western Metalw.*, 1958, **16**, Nov., 45–47) Press extrusion of steel and other metals is briefly reviewed in connexion with missile parts production.

ROLLING MILL PRACTICE

Deformation of steel in rolling with large reductions A. P. Chekmarev, A. A. Dinnik, and V. P. Grechko (*Stal'*, 1958, *Rolling and tube production supplement*, 75–92) Today in a number of plants, the rolling of shapes of varying cross-sections is carried out with a reduction ratio higher than 2 and with angles of bite exceeding the angle of friction. This procedure requires the solution of a number of problems, hence the present theoretical investigation which, together with experimental findings from laboratory experiments and from tests under actual industrial conditions are commented upon.—L. H.

The maximum degree of deformation possible in rolling with plain rolls I. L. Perlin (*Stal'*, *Rolling and tube production supplement*, 1958, 5–9) It is theoretically established that, whatever the diameter of the rolls, there remain ratios of deformation that cannot be obtained. The condition $H < D\,(1 - \cos\rho)$, where H is the thickness of the shape, D the diameter of the roll and ρ the angle of friction, determines the maximum deformation per pass as a function of the angle of bite, and is valid only when, at all points on the arc of the angle of bite, the angle of friction is greater than the angle of bite.—L. H.

Investigating the forward flow and the lag of the metal during rolling B. P. Bakhtinov (*Stal'*, 1958, *Rolling and tube production supplement*, 10–30) The article considers the conception of flow and drag as the slipping of metal on the contact surface, and alternatively as the drawing of metal in the front and rear zones of the deformation. The investigations, based on these conceptions, are then applied to the quantitative determination of the flow and drag in rolling, and formulae are evolved for correction, in the zones of adhesion.—L. H.

Treatment of experimental data regarding the spread when rolling M. I. Zlotnikov (*Stal'*, 1958, *Rolling and tube production supplement*, 63–74) The article is a theoretical analysis of the various formulae evolved by previous investigators concerning the spread in hot and cold rolling and of the margin of error contained in each formula.—L. H.

Investigations to establish a relation between quality of material and the angle of bite in rolling R. Fishgold and I. Dragan (*Studii si Cercetari de Metalurgie*, 1958, (3), 345–358) [In Rumanian] A special apparatus is described for studying qualitatively the influence of the nature of the material on the angle of bite in rolling. This has little direct influence, but indirectly the effect may become important owing to the oxide layers formed during heating. The relations for s.g. cast iron do not differ from those for the usual steels.

The breakdown of steel by hot rolling C. W. Starling (*Sheet Metal Ind.*, 1958, **35**, Nov., 861–871) An outline is given of rolling under theoretically perfect conditions. The simplifying assumptions made are discussed in the light of practical experience. Finally, the effect of various factors on rolling load and torque is considered.—A. G.

Experimental investigation of the rolling process J. Jonca and J. Rabalski (*Hutník*, 1958, **25**, (6), 201–296) Apparatus for automatically recording roll pressures and other factors governing the rolling process is discussed, and theoretical bases outlined. Practical examples of their application are given, and the lessons to be derived are related to present production methods and future plant modernization or replacement.—M. T.

Basis of calculation for angular rolling in plate manufacture O. Emicke and K.-H. Lucas (*Neue Hütte*, 1959, **4**, Feb., 94–100) The authors show that the theoretical considerations developed by Stukatsch for 'angular

rolling' calculations are based on false assumptions and lead to considerable deviations between theory and practice. A new and improved calculation is presented by the authors.

Methods for determining the friction coefficient in rolling A. P. Grudev (*Stal'*, 1958, *Rolling and tube production supplement*, 41–62) This is a theoretical examination of the methods for calculating the friction coefficient: from the maximum angle of bite, from the limiting ratio of reduction, from the friction of strip on the roll, from the forward flow, and from the pressure.—L. H.

The pressure of the metal on the rolls of blooming mills A. P. Chekmarev, V. M. Klimenko, and V. I. Meleshko (*Stal'*, 1958, *Rolling and tube production supplement*, 93–108) The article is a theoretical investigation carried out by the Institute of Ferrous Metallurgy during the last three years at a number of blooming mills to measure the force acting on the rolls and the expenditure of power.

The stress system during transversal and diagonal rolling V. S. Smirnov (*Stal'*, 1958, *Rolling and tube production supplement*, 109–136) For the theoretical analysis of the stress system, the process of transverse and diagonal rolling is considered as a forging action with small reduction and the load on the contact surface is determined, as an approximation, on the assumption of a plane cross-section. Experimental results have proved the validity of these theoretical calculations.—L. H.

The relationship between surface texture and rolling resistance of steel J. Halling (*Brit. J. Appl. Phys.*, 1958, **9**, Nov., 421–428) Surface texture was related to the resistance to rolling of hard steel rollers for ground mild steel specimens. The rolling resistance increased with surface roughness and decreased with load. An empirical law for the relationship is compared with theories of rolling mechanism.

Rolls for rolling trains. 'Steel base' rolls R. A. Villanueva (*Met. Elect.*, 1959, **23**, Feb., 92–95) The composition, structure and manufacture of semi-steel rolls are described.

The effect of carbon content on the properties of soft cast-iron rolls R. Kamenský and L. Toman (*Hutník*, 1958, **8**, (8), 273–277) [In Czech] A statistical analysis of data obtained in the author's plant shows that the hardness of the working surface, the life and other properties are considerably improved by a reduction of the carbon content from 2·6–2·8% to 2·2–2·4%, which results in a reduction in the graphite content as well as in a more favourable mode of distribution of the graphite in the matrix.—P. F.

An effective method of roughening rolling mill rolls M. M. Gorenshtein, N. P. Kologrivov, V. I. Pogorzhel'skii, K. S. Gudovshchikov, and Yu. A. Shapiro (*Metallurg*, 1958, (8), 25–27) Ragging, embossing and knurling of rolling mill rolls considerably improves their gripping power during the first 6–8 12-h periods of working until an erosion network is formed. At the Azovstal' works ragging in the form of short scores 20–30 mm long and 3 mm deep along the line of the axis of blooming mill rolls carried out with a pneumatic chisel and in the first pass a zigzag groove 12–15 mm wide and 3 mm deep in addition to the ragging proved inadequate. A drawing is given of a specially designed knurling tool for use on a roll-turning lathe which produces pyramidal projections 2·5 mm high and 5 × 5 mm at the base, whereby it is claimed that grip is constantly maintained.—M. T.

Contribution towards finding a method of determining the dimensions of safety caps for housings in rolling mills S. Bercu and L. Dragan (*Studii si Cercetari de Metalurgie*, 1958, (4), 505–515) [In Rumanian] The critical forces which have to be considered in rolling determine the dimensions of these caps which must be selected as a function of the admissible resistance of the rolls. The dimensions must be selected to correspond to a force equal to the smallest of the large reactions which result from the acceptable moments of the grooved rolls. Separate caps can be used for different rolls or one cap for a combination of rolls, in which case the calculated dimensions must take into account all admissible reactions to the admissible moments.

A new casting technology for rolling mill stands N. D. Vasil'ev (*Lit. Proizv.*, 1958, (8), 8–9) The new method of casting described is claimed not only to reduce the amount of scrap from runners and risers, but also to produce a very large saving in the use of internal chills.

Antifriction bearings for (rolling mills) British Timkin (*Sci. Lubr.*, 1958, Nov., (extra issue), 59–62) Brief notes on this and other topics.

Rolling pressure and wear of roller bearings for hot- and cold-rolling mills O. Emicke (*Neue Hütte*, 1959, **4**, March, 174–178) A nomogram is presented for heavy-duty roller bearings. The theoretical principles on which it is based are described, and some general observations are offered on its construction.—L. J. L.

Scale on mild steel in various stages of rolling wire rod K. Sachs and G. T. F. Jay (*JISI*, 1959, **193**, Sept., 34–44) [This issue].

PROPERTIES AND TESTS

The measurement of thickness G. Keinath (*NBS Circular* 585, 1958, Jan. 20, pp.79) A review of mechanical methods and devices, of pneumatic, sonic and ultrasonic, displacement gauge, chemical, electrical, heating, capacitance, thermo-electric, magnetic, inductive, optical, X-ray and other radiation gauge methods of determining the thickness of materials of all types (220 refs.).

The workability of cast iron with spheroidal graphite Chang Tso-Mei, Shii U-yung, Gau Tzr-ming, and Kuoh Sheng-chuen (*Scientia Sinica*, 1959, **8**, Jan., 110–131) Iron as-cast and annealed was examined by tensile, compression, impact, torsion, upsetting and rolling tests. The best working temperature was found to lie between 700–1100°C depending on the stress system used and the rate of working. The maximum amount of working permissible was also found. Industrial scale tests correlated best with upsetting and rolling.

An investigation into the structure and properties of high-pressure steam pipes after prolonged operation in power plants E. S. Ginzburg (**The Strength of Metals*, *Moscow, Akad. Nauk*, 1956, 58–66) Microstructure, mechanical properties, creep-resistance and long-term tensile and impact strength were observed after 38 000–53 000 h operation at ~ 490°C and 100 atm. The location of the pipes and their analyses are given. One pipe showed cold-brittleness but the properties of the others were still satisfactory. High carbon content was apparently the cause of reduced impact strength in one case, but even the creep properties of this specimen remained adequate.

The plasticity of cast iron at elevated temperatures O. Yu. Kotsyubinskii (*Lit. Proizv.*, 1958, (8), 15–16) Experiments were carried out on the relative plastic deformation of cylindrical specimens, 15 mm dia., 150 mm long, at temperatures up to 800°C, produced over periods up to 30 min from the moment at which the metal started to yield, and a criterion, K_p, was evolved for the plasticity of the material. Experiments were also carried out on strain release in the same materials, and it is shown that there is a relationship between the factor, K_p, and the rate and extent of the strain release. When three values of K_p are plotted against stress-temperature coordinates, three zones are apparent: in the low-temperature zone the metal is completely resistant to deformation and high internal stresses are set up; in the high-temperature zone the metal is highly plastic and internal stresses are quickly dispersed; and a transition zone in which plasticity and strain release acquire increasing values with the increase in temperature. The transition zone for cast iron is shown to extend from about 375° to 800°C, and not to be a fixed temperature of 800°C (*cf.* Heine). Its limits vary in proportion to the value of the internal stresses created by deformation.

Investigation of mechanical properties of heat-treated instrumental steels Z. M. Konyushko (*Vestnik Mashin.*, 1955, (12), 47–51) Specimens of five different types of instrument steels were investigated and the elastic constants of the materials determined – moduli of elasticity of the first and second order, *E. G.* and Poisson's ratio. A special tensometer had to be used with these steels registering 0·002 mm with a x 500 amplification. The results are tabulated.—L. H.

The effect of specimen size on tensile properties of a coarse-grained medium-carbon steel at low temperatures T. Williams and H. F. Hall (*JISI*, 1959, **193**, Sept., 56–60) [This issue].

Hot-ductility of the austenitic stainless steels. Study on the hot-ductility of steels. II T. Morishima (*Tetsu to Hagane*, 1958, **44**, June, 660–668) For types 304 and 316 stainless steels, hot-twist values gave a close correlation with pierceability by the Mannesmann piercer. Hot-ductility decreased with increase of oxygen content, and was poor with steel having the $(\gamma + \alpha)$ phase at high temperature.—K. E. J.

Influence of static stress and temperature on internal damping J. W. Clark and W. C. Hagel (*Trans. ASM*, 1958, **52**, preprint 118, pp.15) Damping in austenitic alloys and Ti were measured at stresses from zero to 35 000 psi at static tension stresses from zero to 19 000 psi and at temperatures from 75–1 100°F. The damping of AIS 1–403 at 500–700°F and 19 000 psi static stress is reduced by more than an order of magnitude from that at zero static stress and 75°F. The internal damping of Ti is small under all test conditions.

Residual stresses in metals and their determination. I. General. Methods of determination J. M. Sistiaga (*Rev. Ciencia Apl.*, 1958, **12**, Sept.–Oct., 385–396) This section deals with general principles, and the determinaton of residual stresses in a cylinder.

Residual stresses in metals, and their determination. II. Methods of determination: Conclusions J. M. Sistiaga (*Rev. Ciencia Apl.*, 1958, **12**, (6), 496–507) The theory and practice of the determination of residual stresses in flat elements are discussed; several cases of residual stress are discussed, and methods for determining triaxial stresses are examined. Procedures based on X-ray diffraction are described (115 refs.).

Seminar on residual stresses R. Weck (*ASM meeting at Cleveland, Ohio*, Oct.-Nov. 1958, pp.67) A non-mathematical discussion of the concept of strain in a solid without external stress is developed. Methods of measurement are reviewed and the special theoretical difficulties are pointed out concerning not only assessment but also interpretation and even value. The effects of internal stress on deformation, static carrying capacity, stability and machining stability are then considered and further extended to fatigue strength and stress corrosion effects. The bearing on brittle fracture is then taken up. Finally, the methods of stress relief are surveyed – the mathematical theory is added as an appendix.

The determination of initial stresses in steel plates C. Riparbelli, E. W. Suppiger, and E. R. Ward (*Ship Structure Committee Project, SR-113, Final Report: SSC–42*, 1958, Sept. 15 pp.48) The determination of direction and magnitude of principal stresses at any location in a structure are measured by attaching strain-gauges around the point and then drilling a hole there. Stresses were measured in test plates with known values up to 15 000 psi and a precision of ± 1000 psi was attained. Repair of the holes is simple.

On the number of 3*d* electrons in iron C. Kittel and W. Marshall (*Phys. Chem. Solids*, 1958, **6**, July, 99) A letter. A comment on the value for total *d*-electrons of 2·3 + 0·3 found by Weiss and De Marco and its reconciliation with the *g*-2 and 2-*g*′ terms from microwave resonance.

The measurement of the strain-dependent damping of metals vibrating torsionally G. Sumner and K. M. Entwistle (*Brit. J. Appl. Phys.*, 1958, **9**, Nov., 434–438) Apparatus is described for measurements up to $\sim 2 + 10^{-3}$ shear strains for mild steel.

A photoelectric load monitor for rapid tensile testing B. F. Billing (*Royal Aircraft Establishment Tech. Note No. MET.* 293, 1958, July, pp.7) In testing of high rates of loading a limiting factor was the reading of the load indicator. A photo-transistor arrangement was therefore fitted to the pointer of the 5 000 lb testing machine and used to monitor uniform load increments with camera recording of optical extensometer readings. Up to five readings per sec could be made reliably (above nine

it became erratic) and 2% or 1% load increments were recorded.

Machine for investigating microspecimens for tensile strength at high temperatures *in vacuo* V. P. Konoplenko and D. K. Vinogradov (*Zavods. Lab.*, 1959, (1), 106–108) A description and diagrammatic drawing of the machine IRM–0·2 MIFI is given showing its construction and working principle. The machine determines yield and tensile strength, relative elongation and reduction of area *in vacuo* and in various atmospheres up to 1·5 atm pressures and up to 1 200°C.

The effect of alloying mild steel upon its resistance to stress-corrosion cracking R. N. Parkins and A. Brown (*JISI*, 1959, **193,** Sept., 45–47) [This issue].

METALLOGRAPHY

The metallographic testing of high speed steels O. Felgel-Farnholz (*Berg.-Hütten. Monatsh.*, 1958, **103,** Nov., 223–230) The suitability of quantitative metallographic examination for the routine testing of high speed steels is pointed out, and examples are given of such testing at various stages of manufacture – as-cast structure, billet, bar and finished tool.

Contributions to iron-works chemistry: Metallurgical examination (1953 to the end of 1958) H. Sundermann (*Stahl Eisen*, 1959, **79,** Jan. 22, 95–98) This type of metallurgical examination is reviewed under the headings of Direct Methods and Isolation Methods. Electrolytic methods and potentiostatic isolation, phase separation, the estimation of oxides, sulphides, nitrides, carbides and the examination of structure are dealt with in turn (95 references). —T. G.

A combined electrolytic polisher and microscope F. Rümmele (*Eng. Digest*, 1958, **19,** Nov., 479–481) An instrument developed by the Zeiss Co. is described, by means of which the surface of a specimen can be observed continuously during electrolytic polishing.

Grain boundaries and the thermal etching of iron E. R. Hayward and A. P. Greenhough (*JISI*, 1959, **193,** Sept., 32–33) [This issue]

A universal electrolyte for polishing metallurgical specimens in heat resisting, stainless and low-carbon steels and titanium alloys G. I. Parfessa and V. A. Sidlyarenko (*Avtom. Svarka*, 1958, **11,** (7), 82) Electrolytic polishing of specimens can be carried out much more rapidly than mechanical polishing. For polishing specimens of 18–8; 25–20; 15–35; Cr 20–Mo; Cr 15–Mo; and low-carbon steels and Ti alloys an electrolyte of the following composition was used: 500 cm³ glacial acetic acid, 16·5 cm³ perchloric acid. Electrolysis was carried out with voltage 120 V, current density 0·30–0·25 A/cm²; distance between anode and cathode, 12–15 mm, time of electrolysis, 3–8 sec. The electrolyte should be carefully prepared by adding small quantities of the perchloric acid to the glacial acetic while the electrolyte is stirred and cooled.—M.T.

Non-metallic inclusions in steel N. Parau (*Met. Constr. Masini*, 1958, (11), 947–952) [In Rumanian] The non-metallic inclusions in steel are discussed generally, such as the number of inclusions and their appearance, and a criterion is given for determining the degree of purity of the steel.

Microradiographic method of quantitative absorption by chemical non-uniformities in alloys B. A. Movchan (*Zavods. Lab.*, 1959, (1), 68–70) When microradiographing on fine-grain photographic plates a standard specimen of the base metal is placed together with the specimen of the alloy which is to be investigated. On developing the plate, regions of different intensities of black appear and these are interpreted according to standards derived from formulae based on the fact that the intensity of blackening is proportional to the intensity of the X-rays. This method was tested on binary and ternary alloys and has shown an accuracy of ±10–15%.

Isolation of carbides in high-alloy steels in bromide solutions H. Tuma (*Hutn. Listy*, 1958, **8,** (8), 717–719) Investigation of structural changes in such steels after heat treatment is conveniently carried out by isolation and analysis of the carbides. An experimental comparison was made between electrolytic isolation and isolation in bromine solutions. The stability of pure carbides was investigated in 10% Br solutions in distilled water, methyl alcohol and methyl acetate, i.e. in a neutral anhydrous medium. It was found that these solutions cannot be used for steels containing Mo or V but electrolytic isolation must be used. Isolation from steels not containing Mo or V is possible in an aqueous solution of Br, and this was more effective than electrolytic isolation. The methanol solution was still more effective, but cannot be used for steels containing Fe_3C, Mo, or V; again for steels containing W it may be assumed that inaccuracies will occur. Methyl acetate solutions are unsuitable in all instances. The stability and resistance of carbides to isolation in these solutions increases with the Cr content of the steel.—M. T.

The study of the non-metallic inclusions. II. The distribution of sand marks on the periphery and the centre of bearing rods and pipes observed by gradually cutting away M. Kawai and H. Kimura (*Tetsu to Hagane*, 1958, **44,** July, 740–744) By gradual cutting of steel rods, it is shown that the number of sand marks on any surface remains almost constant, although many larger marks exist at the periphery. Sand marks are elongated by rolling the rods. They do not disappear with severe hot work, e.g. pipe-making or extrusion.

Study of the carbides in iron and steel by electrolytic isolation. VIII. Carbides in tungsten steel T. Sato, T. Nishizawa, and M. Ohashi (*Nippon Kinzoku*, 1957, **21,** Nov., 662–665). The Curie point of $M_{23}C_6$ varies from 150° to 400°C, depending on composition and thermal history. The η^*-carbide was observed in low-C high-W steels; it is considered to be $M_{12}C$, formed from M_6C (16 references). **IX. Decomposition processes of $M_{23}C_6$ in tungsten steels** (1958, **22,** Mar., 141–144) The decomposition of $M_{23}C_6$ during subcritical annealing was studied by several methods. Carbide products may be (i) M_6C or (ii) WC. The addition of Si and Ti to tungsten steel accelerates (i), and Co and Ni (ii), while Cr, Mo and V retard the decomposition. The 'spoiling' in tungsten magnet steels should be considered as a form of this decomposition.—K. E. J.

Behaviour of the carbides and heat-treatment in low-tungsten and low-tungsten cobalt high-speed steels. (Study of the carbides in high-speed steels by electrolytic isolation – I) S. Koshiba, S. Kimura, and H. Harada (*Tetsu to Hagane*, 1958, **44,** Oct., 1186–1191) The authors studied the behaviour of carbides in low-W and in low-W–Co high-speed steels containing about 11%W, 4%Cr, 1·8% V and 4·4%Co. The carbides were isolated by the Klinger and Koch method and the chemical composition and crystal structures determined by chemical analysis and X-ray diffraction, the shapes were observed in the electron microscope. The relation between temperature, quantity of carbides and hardness was also examined.—T. G.

Carbides in annealed and quenched high-speed steels T. Malkiewicz, Z. Bojarski, and J. Foryst (*JISI*, 1959, **193,** Sept., 25–31) [This issue].

Investigation of the dispersion of ferromagnetic precipitates in austenitic alloys by means of demagnetization curves N. I. Eremin (*Metallov. Obra. Met.*, 1958, (7), 27–30) The dispersion of ferromagnetic precipitates in austenite (in 18–18 Cr–Ni steel specimens) was calculated from the demagnetisation curves. To vary the dispersion, the specimens were first cold worked, 10, 25 and 40% extension. The concept of single-domain precipitates makes it possible to estimate the physical constants of the precipitates from the demagnetization curves and therefore also the variations in the hardness of the alloys.—L. R.

On the recrystallization of deformed metals and alloys Ya. R. Rauzin (*Metallov. Obra. Met.*, 1958, (4), 52–60) This is a survey of the literature referring mainly to work done abroad (51 refs.).

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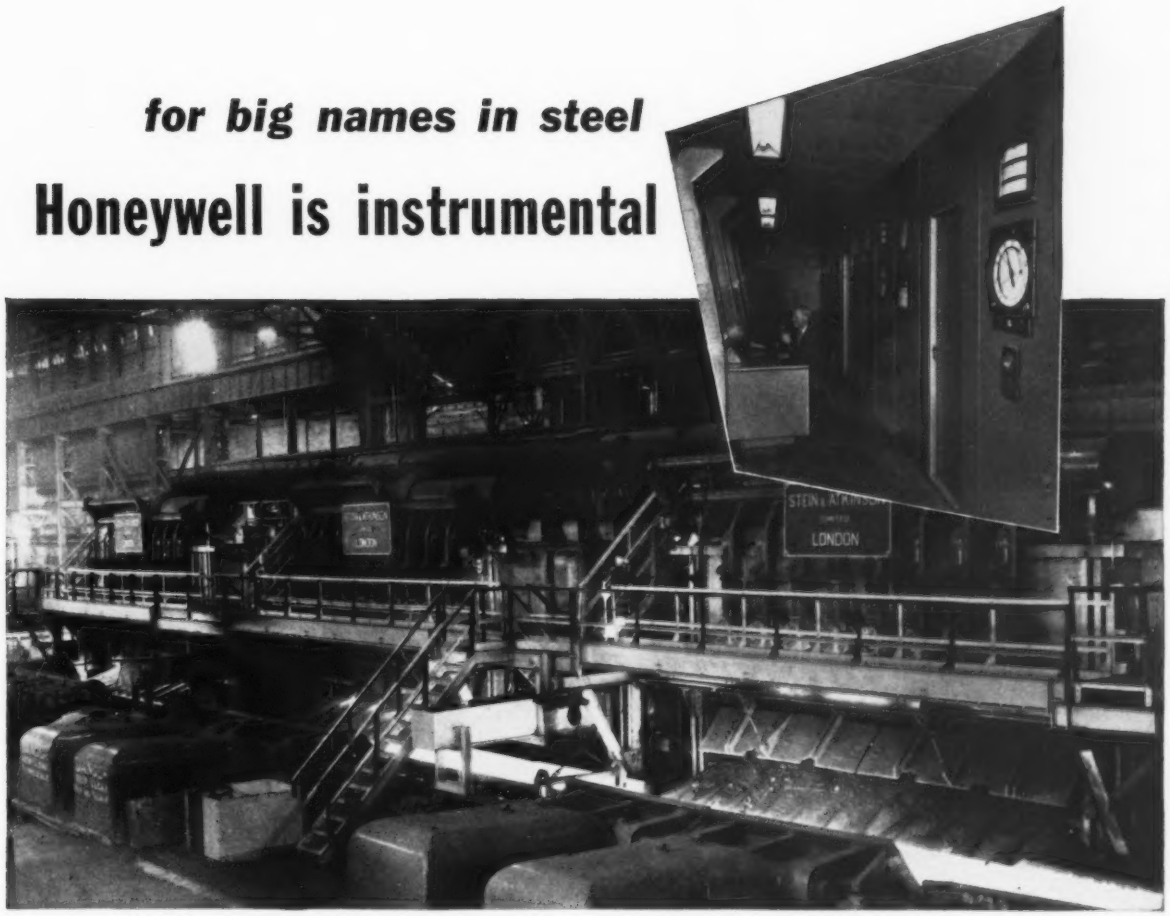

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it became erratic) and 2% or 1% load increments were recorded.

Machine for investigating microspecimens for tensile strength at high temperatures *in vacuo* V. P. Konoplenko and D. K. Vinogradov (*Zavods. Lab.*, 1959, (1), 106–108) A description and diagrammatic drawing of the machine IRM–0·2 MIFI is given showing its construction and working principle. The machine determines yield and tensile strength, relative elongation and reduction of area *in vacuo* and in various atmospheres up to 1·5 atm pressures and up to 1 200°C.

The effect of alloying mild steel upon its resistance to stress-corrosion cracking R. N. Parkins and A. Brown (*JISI*, 1959, **193**, Sept., 45–47) [This issue].

METALLOGRAPHY

The metallographic testing of high speed steels O. Felgel-Farnholz (*Berg.-Hütten. Monatsh.*, 1958, **103**, Nov., 223–230) The suitability of quantitative metallographic examination for the routine testing of high speed steels is pointed out, and examples are given of such testing at various stages of manufacture – as-cast structure, billet, bar and finished tool.

Contributions to iron-works chemistry: Metallurgical examination (1953 to the end of 1958) H. Sundermann (*Stahl Eisen*, 1959, **79**, Jan. 22, 95–98) This type of metallurgical examination is reviewed under the headings of Direct Methods and Isolation Methods. Electrolytic methods and potentiostatic isolation, phase separation, the estimation of oxides, sulphides, nitrides, carbides and the examination of structure are dealt with in turn (95 references).—T. G.

A combined electrolytic polisher and microscope F. Rümmele (*Eng. Digest*, 1958, **19**, Nov., 479–481) An instrument developed by the Zeiss Co. is described, by means of which the surface of a specimen can be observed continuously during electrolytic polishing.

Grain boundaries and the thermal etching of iron E. R. Hayward and A. P. Greenhough (*JISI*, 1959, **193**, Sept., 32–33) [This issue]

A universal electrolyte for polishing metallurgical specimens in heat resisting, stainless and low-carbon steels and titanium alloys G. I. Parfessa and V. A. Sidlyarenko (*Avtom. Svarka*, 1958, **11**, (7), 82) Electrolytic polishing of specimens can be carried out much more rapidly than mechanical polishing. For polishing specimens of 18–8; 25–20; 15–35; Cr 20–Mo; Cr 15–Mo; and low-carbon steels and Ti alloys an electrolyte of the following composition was used: 500 cm³ glacial acetic acid, 16·5 cm³ perchloric acid. Electrolysis was carried out with voltage 120 V, current density 0·30–0·25 A/cm²; distance between anode and cathode, 12–15 mm, time of electrolysis, 3–8 sec. The electrolyte should be carefully prepared by adding small quantities of the perchloric acid to the glacial acetic while the electrolyte is stirred and cooled.—M.T.

Non-metallic inclusions in steel N. Parau (*Met. Constr. Masini*, 1958, (11), 947–952) [In Rumanian] The non-metallic inclusions in steel are discussed generally, such as the number of inclusions and their appearance, and a criterion is given for determining the degree of purity of the steel.

Microradiographic method of quantitative absorption by chemical non-uniformities in alloys B. A. Movchan (*Zavods. Lab.*, 1959, (1), 68–70) When microradiographing on fine-grain photographic plates a standard specimen of the base metal is placed together with the specimen of the alloy which is to be investigated. On developing the plate, regions of different intensities of black appear and these are interpreted according to standards derived from formulae based on the fact that the intensity of blackening is proportional to the intensity of the X-rays. This method was tested on binary and ternary alloys and has shown an accuracy of ±10–15%.

Isolation of carbides in high-alloy steels in bromide solutions H. Tuma (*Hutn. Listy*, 1958, **8**, (8), 717–719) Investigation of structural changes in such steels after heat treatment is conveniently carried out by isolation and analysis of the carbides. An experimental comparison was made between electrolytic isolation and isolation in bromine solutions. The stability of pure carbides was investigated in 10% Br solutions in distilled water, methyl alcohol and methyl acetate, i.e. in a neutral anhydrous medium. It was found that these solutions cannot be used for steels containing Mo or V but electrolytic isolation must be used. Isolation from steels not containing Mo or V is possible in an aqueous solution of Br, and this was more effective than electrolytic isolation. The methanol solution was still more effective, but cannot be used for steels containing Fe_3C, Mo, or V; again for steels containing W it may be assumed that inaccuracies will occur. Methyl acetate solutions are unsuitable in all instances. The stability and resistance of carbides to isolation in these solutions increases with the Cr content of the steel.—M. T.

The study of the non-metallic inclusions. II. The distribution of sand marks on the periphery and the centre of bearing rods and pipes observed by gradually cutting away M. Kawai and H. Kimura (*Tetsu to Hagane*, 1958, **44**, July, 740–744) By gradual cutting of steel rods, it is shown that the number of sand marks on any surface remains almost constant, although many larger marks exist at the periphery. Sand marks are elongated by rolling the rods. They do not disappear with severe hot work, e.g. pipe-making or extrusion.

Study of the carbides in iron and steel by electrolytic isolation. VIII. Carbides in tungsten steel T. Sato, T. Nishizawa, and M. Ohashi (*Nippon Kinzoku*, 1957, **21**, Nov., 662–665). The Curie point of $M_{23}C_6$ varies from 150° to 400°C, depending on composition and thermal history. The η^*-carbide was observed in low-C high-W steels; it is considered to be $M_{12}C$, formed from M_6C (16 references). **IX. Decomcomposition processes of $M_{23}C_6$ in tungsten steels** (1958, **22**, Mar., 141–144) The decomposition of $M_{23}C_6$ during subcritical annealing was studied by several methods. Carbide products may be (i) M_6C or (ii) WC. The addition of Si and Ti to tungsten steel accelerates (i), and Co and Ni (ii), while Cr, Mo and V retard the decomposition. The 'spoiling' in tungsten magnet steels should be considered as a form of this decomposition.—K. E. J.

Behaviour of the carbides and heat-treatment in low-tungsten and low-tungsten–cobalt high-speed steels. (Study of the carbides in high-speed steels by electrolytic isolation – I) S. Koshiba, S. Kimura, and H. Harada (*Tetsu to Hagane*, 1958, **44**, Oct., 1186–1191) The authors studied the behaviour of carbides in low-W and in low-W–Co high-speed steels containing about 11%W, 4%Cr, 1·8% V and 4·4%Co. The carbides were isolated by the Klinger and Koch method and the chemical composition and crystal structures determined by chemical analysis and X-ray diffraction, the shapes were observed in the electron microscope. The relation between temperature, quantity of carbides and hardness was also examined.—T. G.

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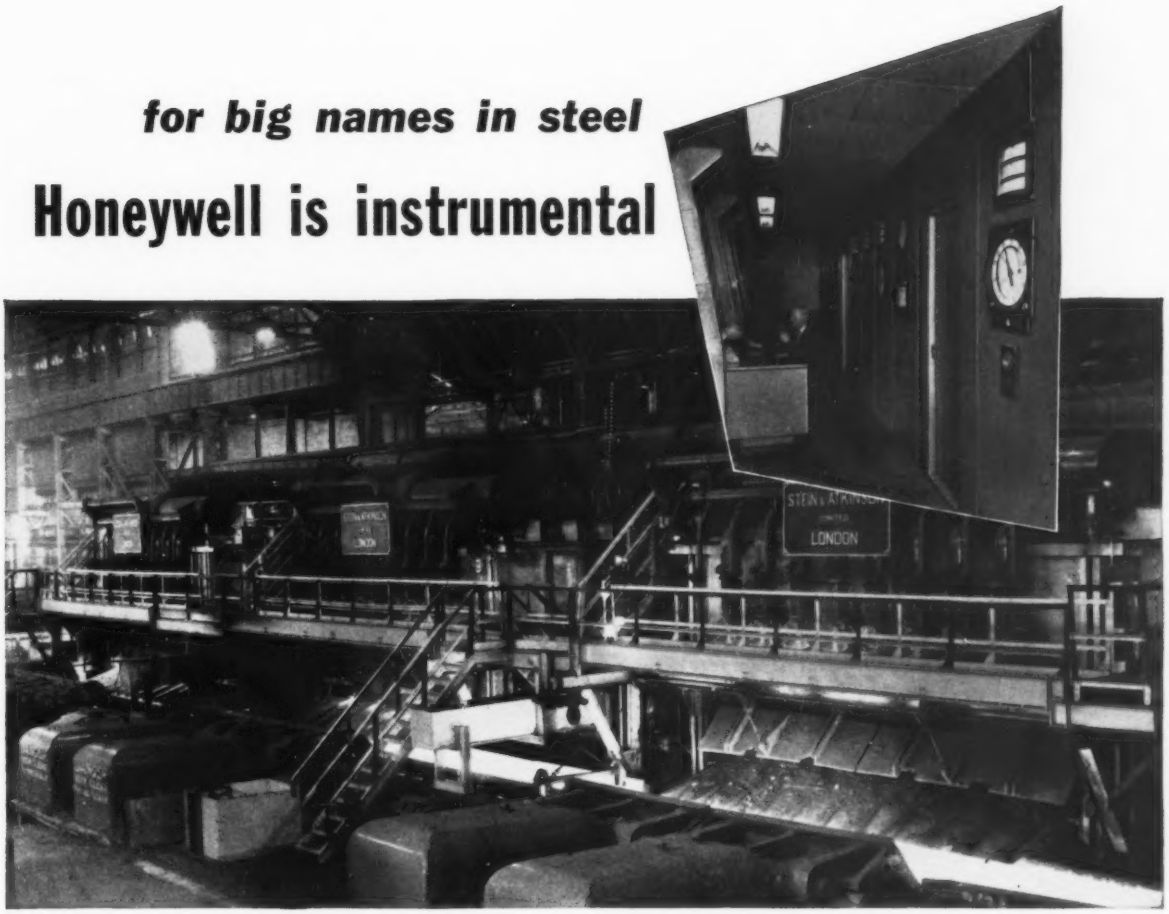

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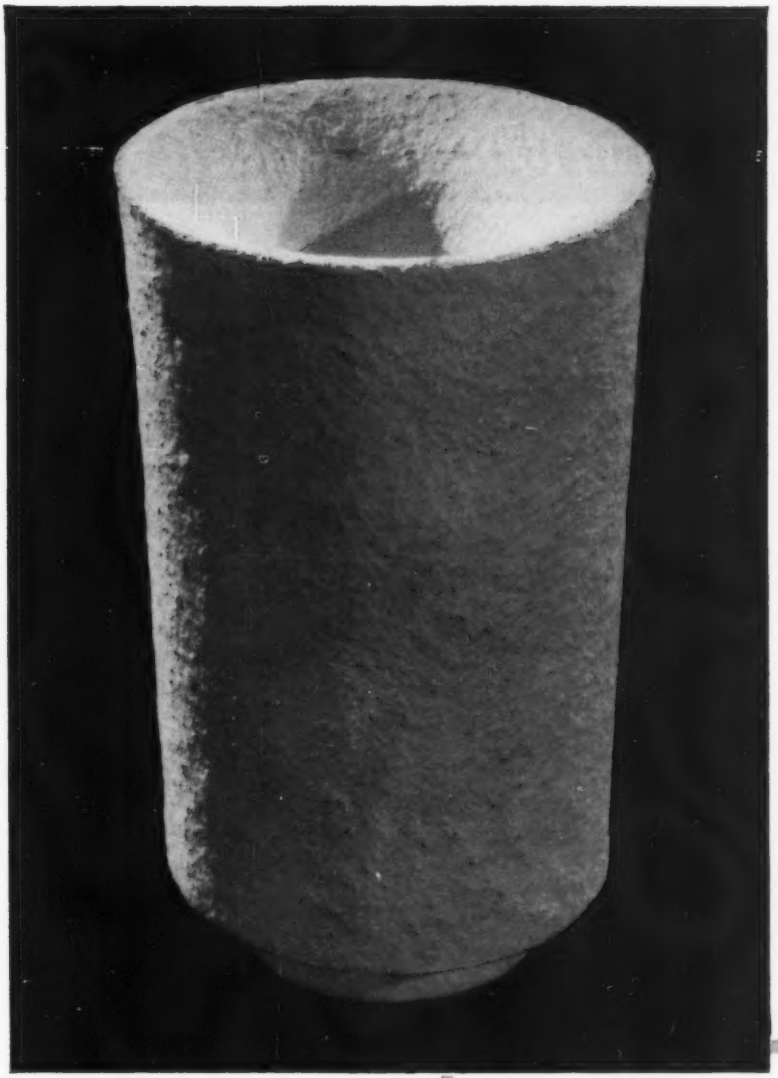

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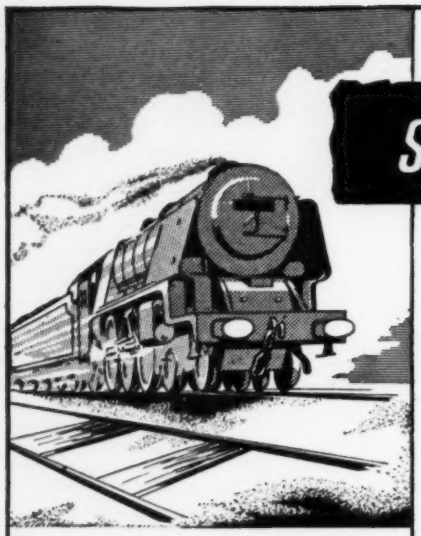

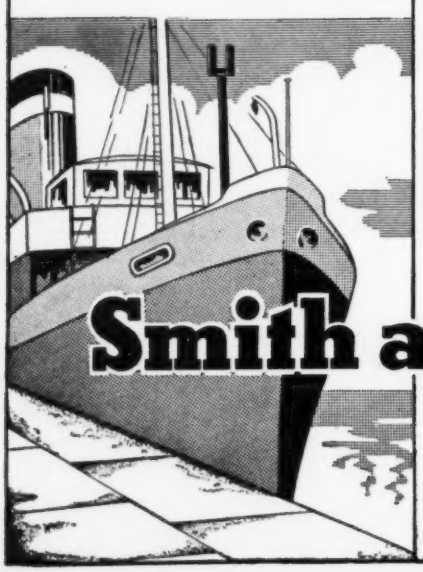

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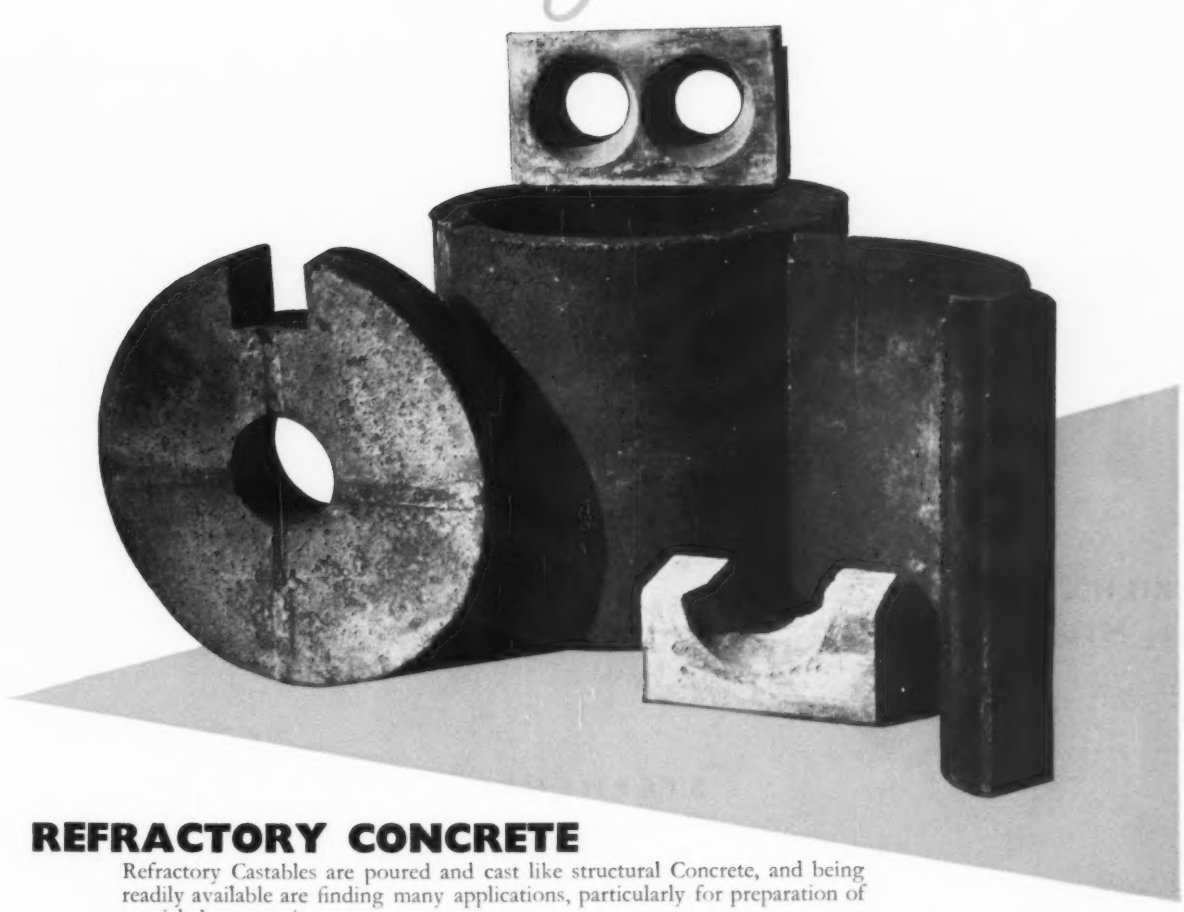

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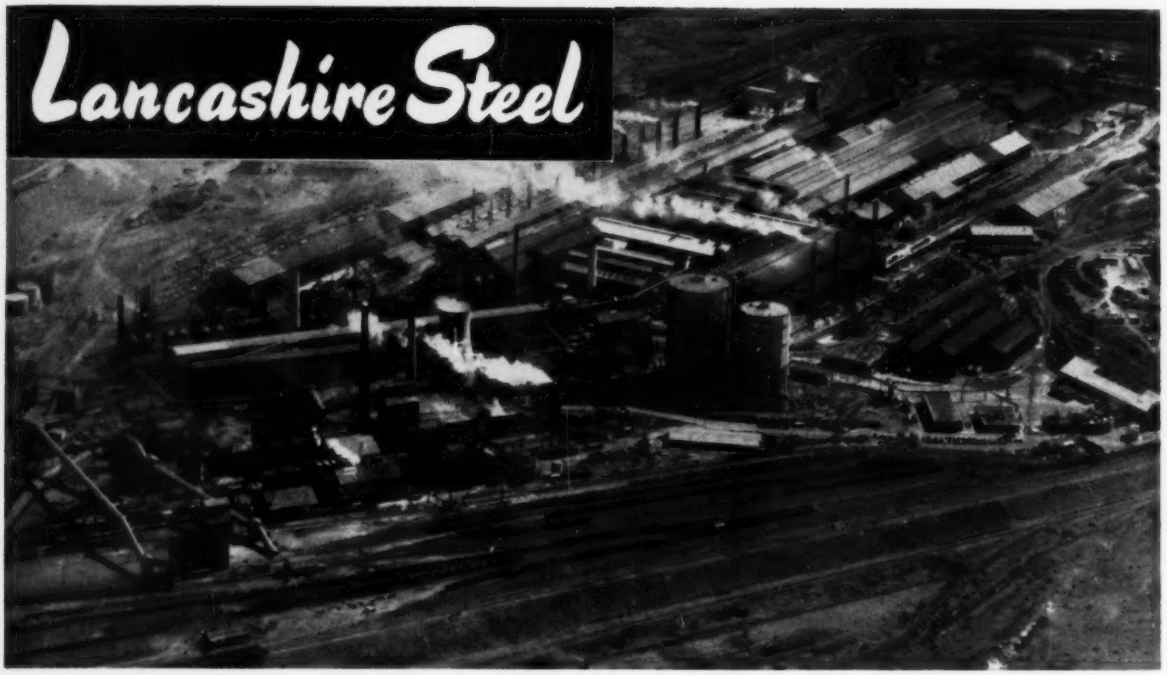

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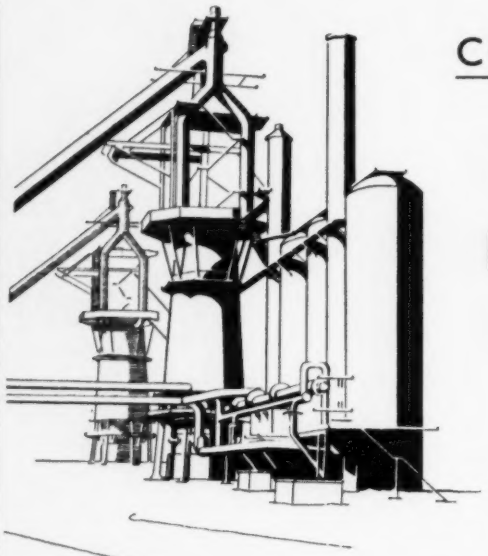

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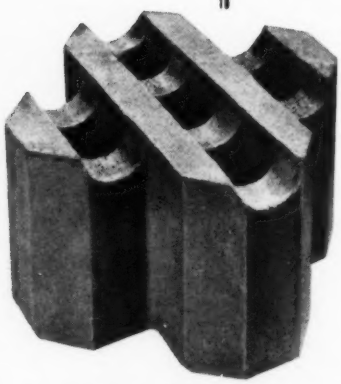

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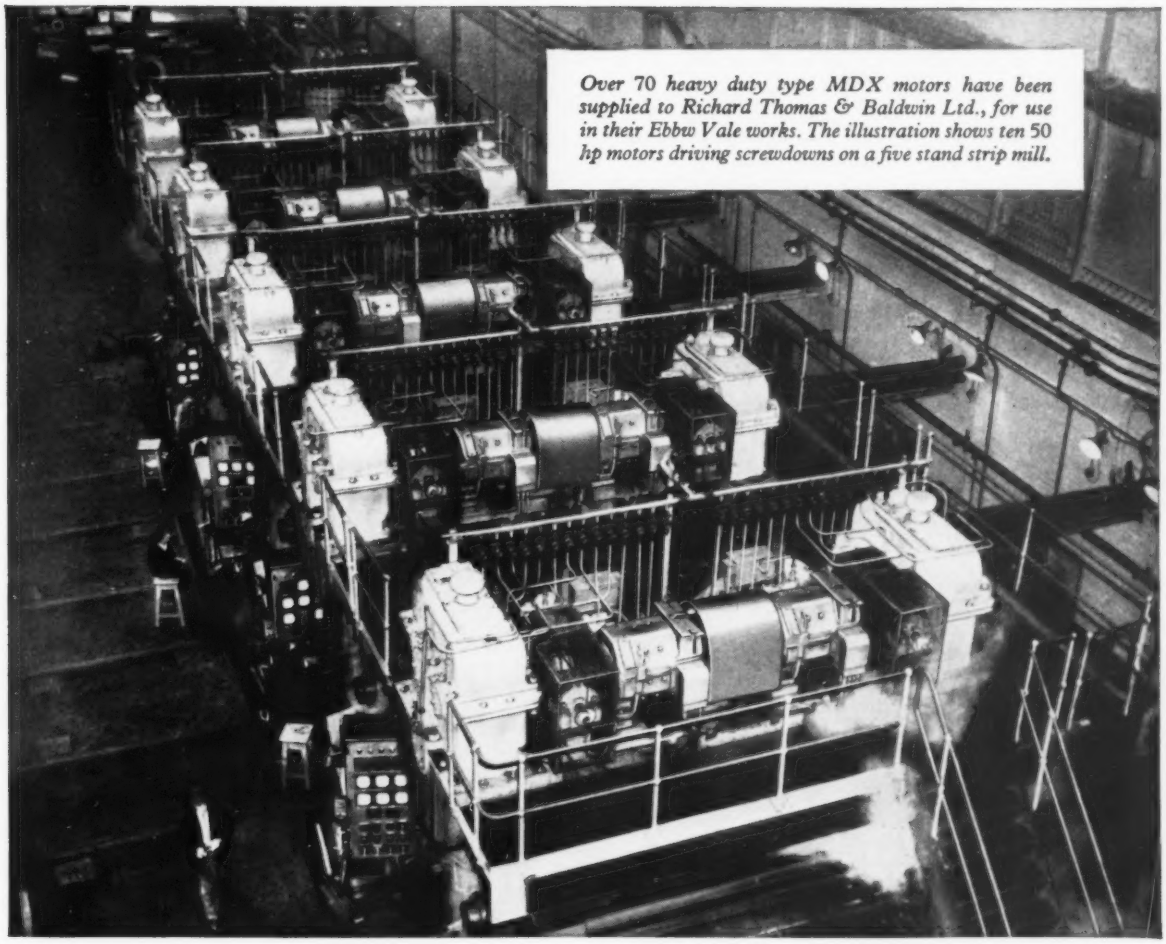

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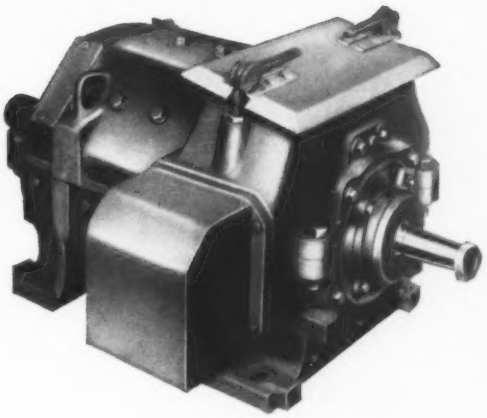

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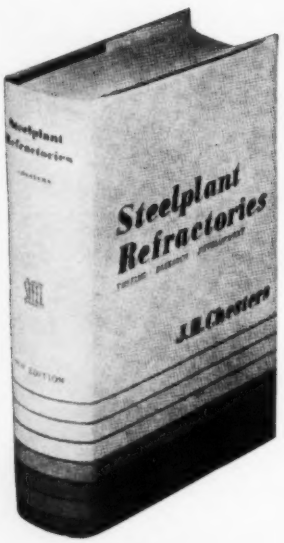

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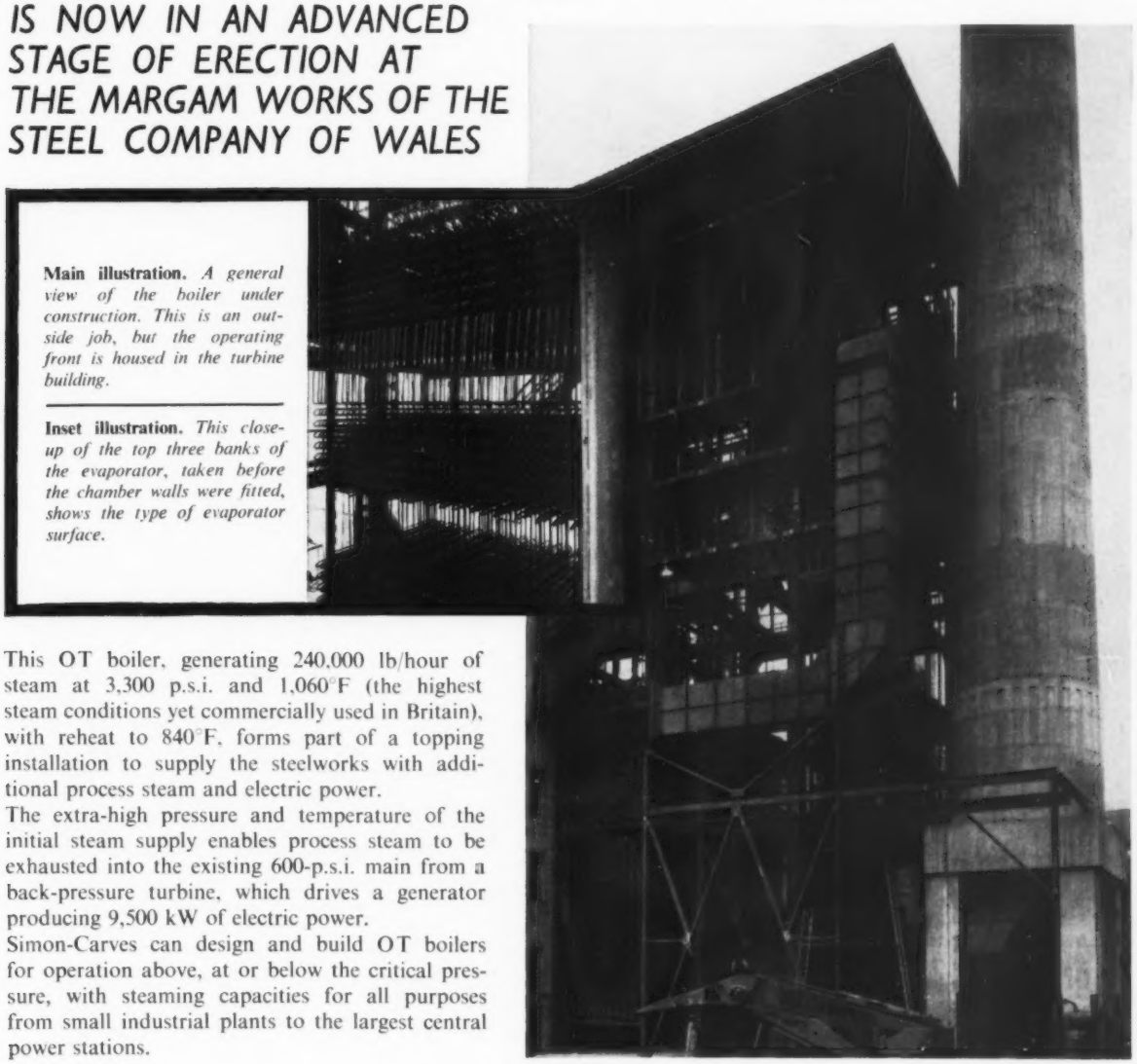

Main illustration. *A general view of the boiler under construction. This is an outside job, but the operating front is housed in the turbine building.*

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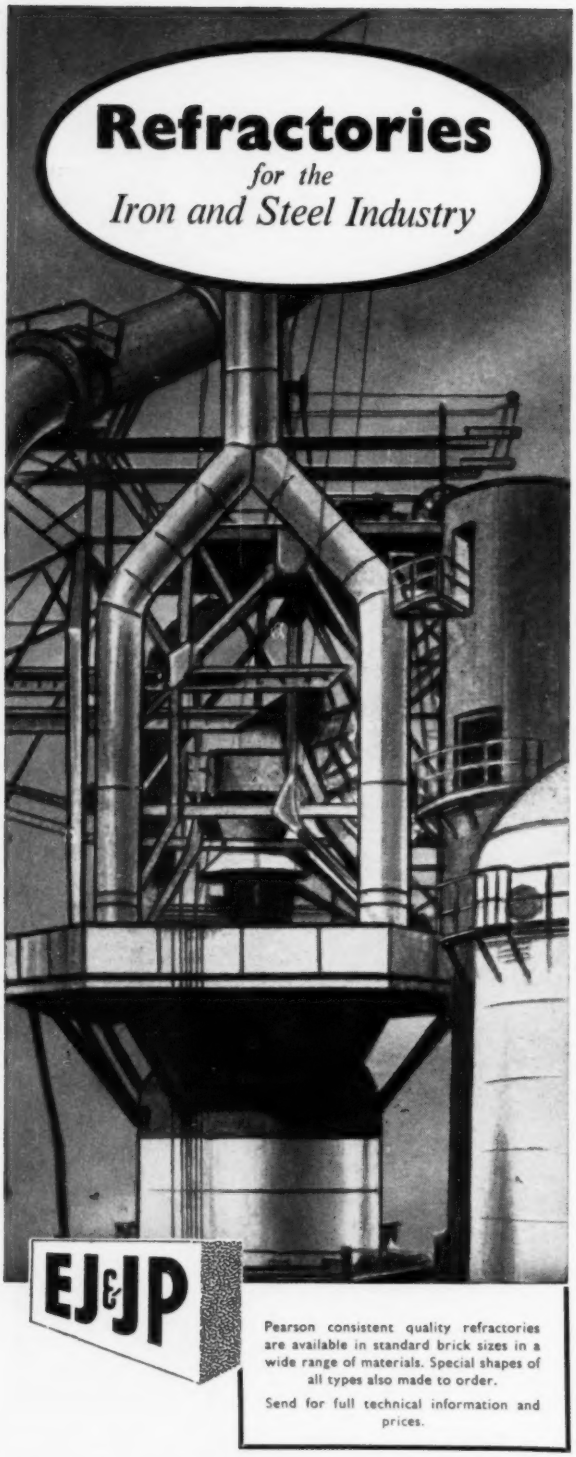
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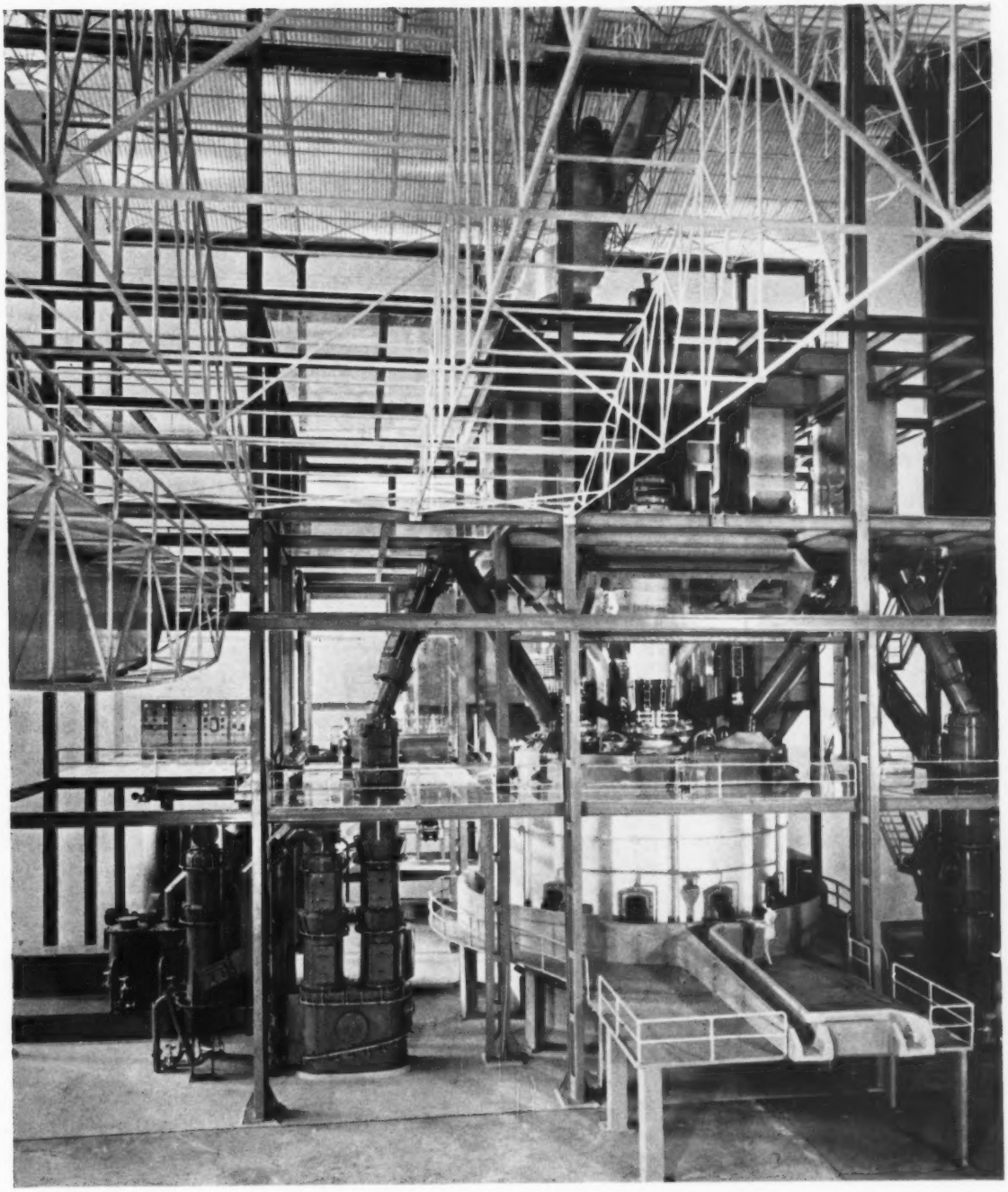

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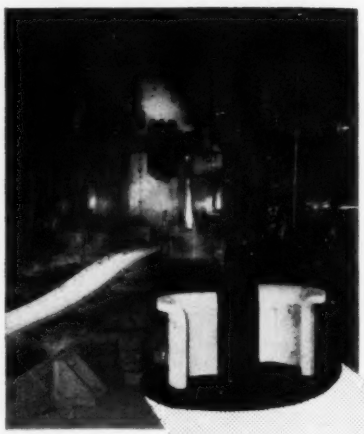

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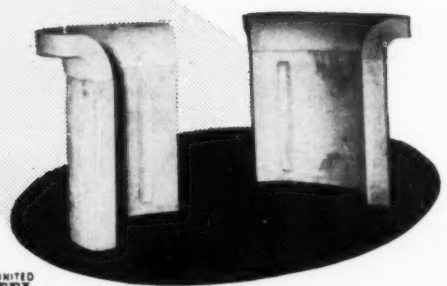

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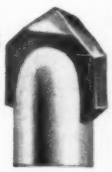

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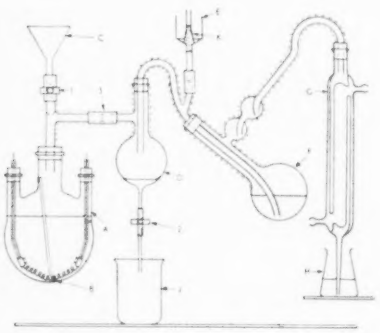

Great interest has always been shown in the role of nitrogen in determining the properties of ferrous alloys. Reliable and accurate methods are therefore necessary for determining the content of this element in alloys.

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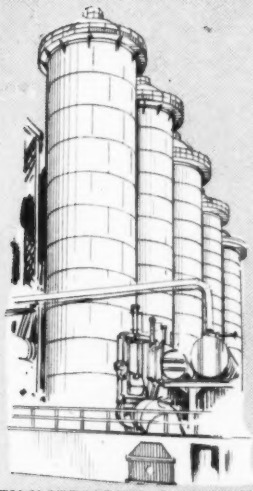

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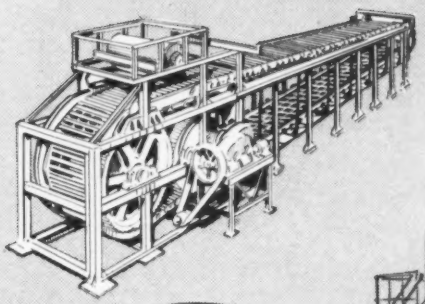

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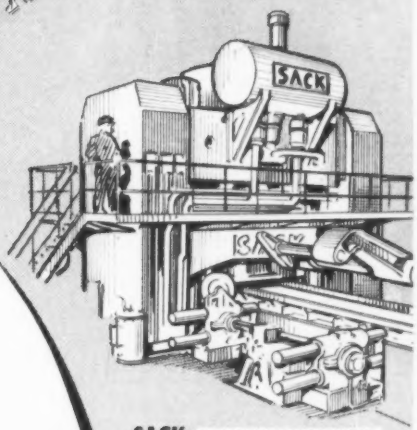

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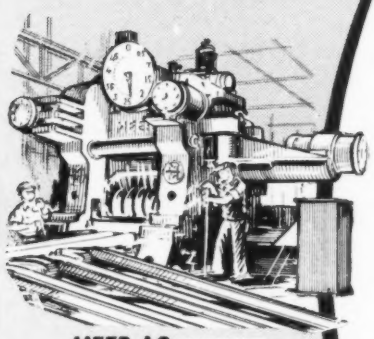

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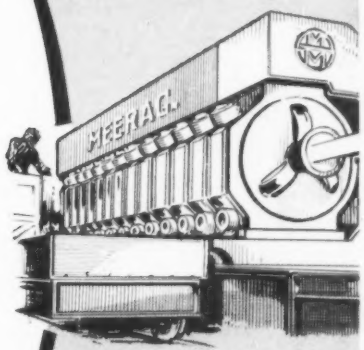

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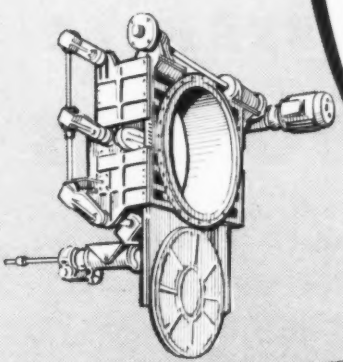

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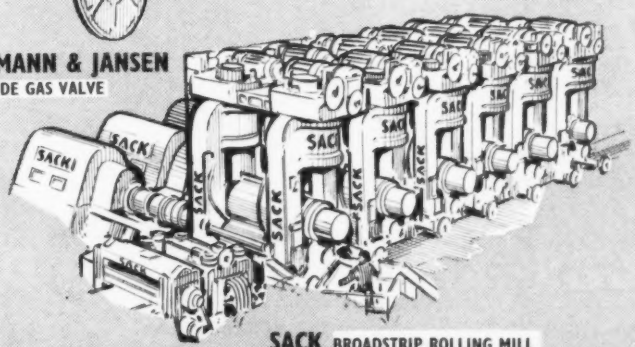

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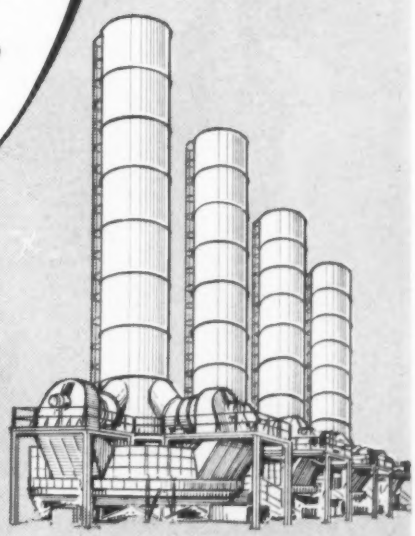

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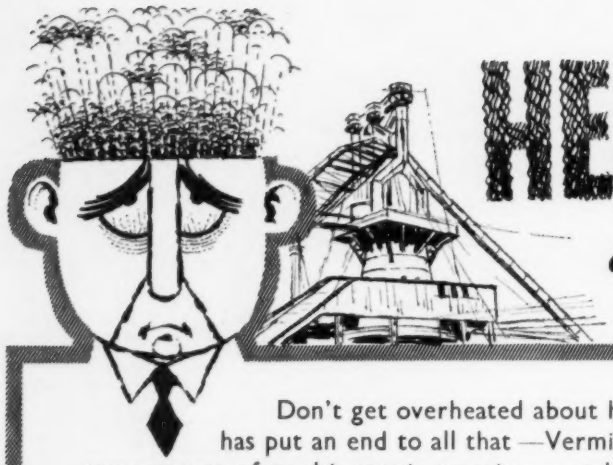

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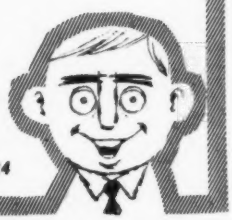

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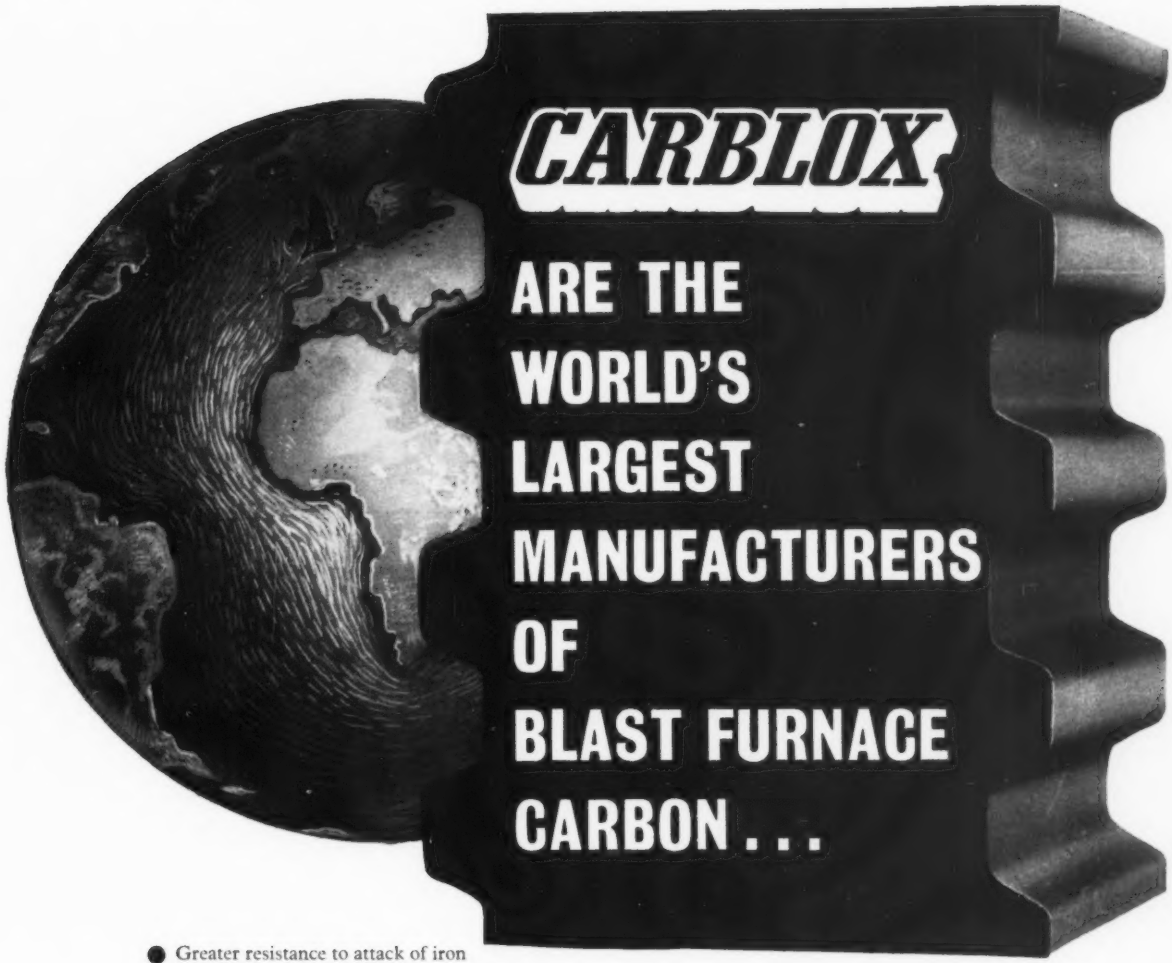

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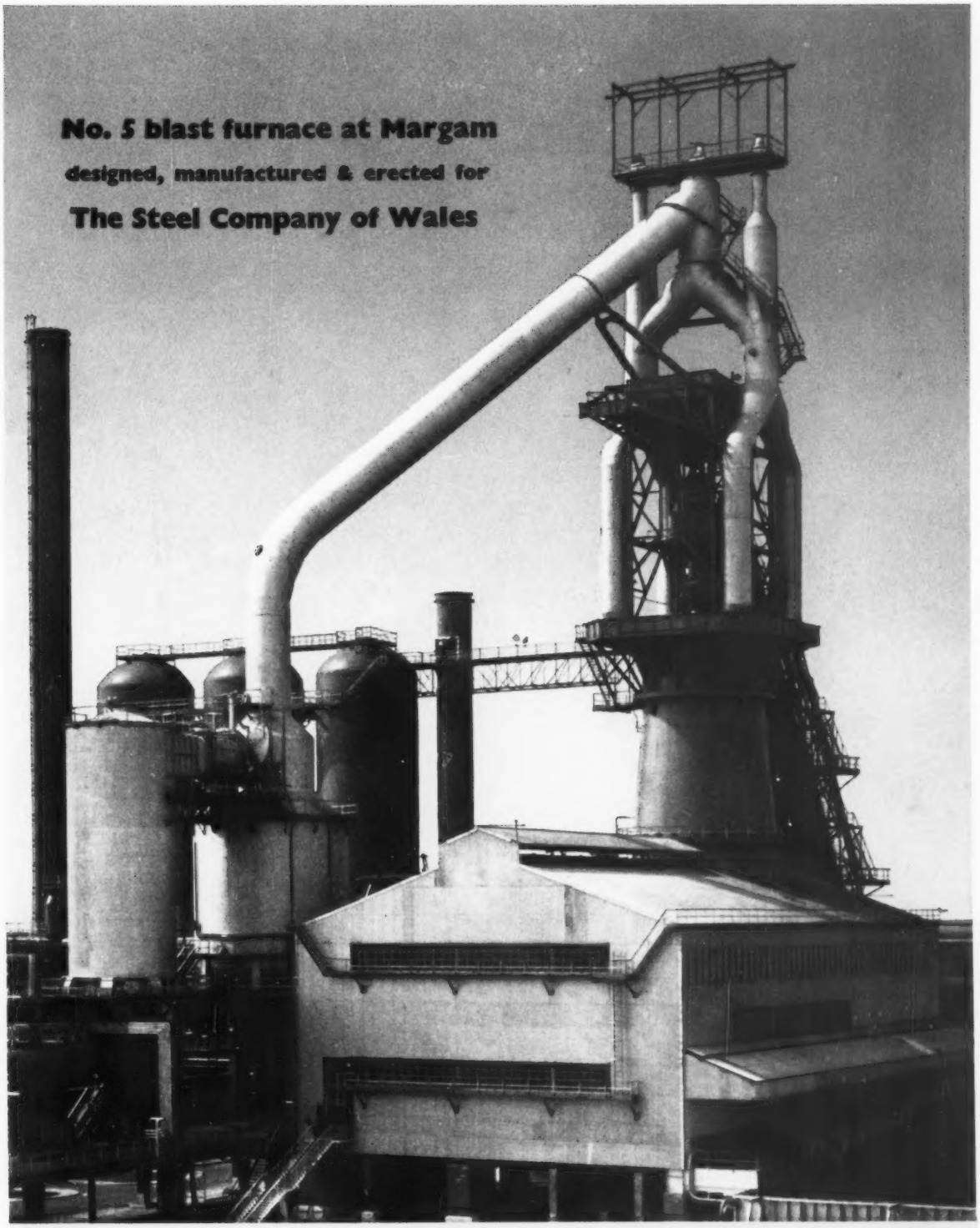

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